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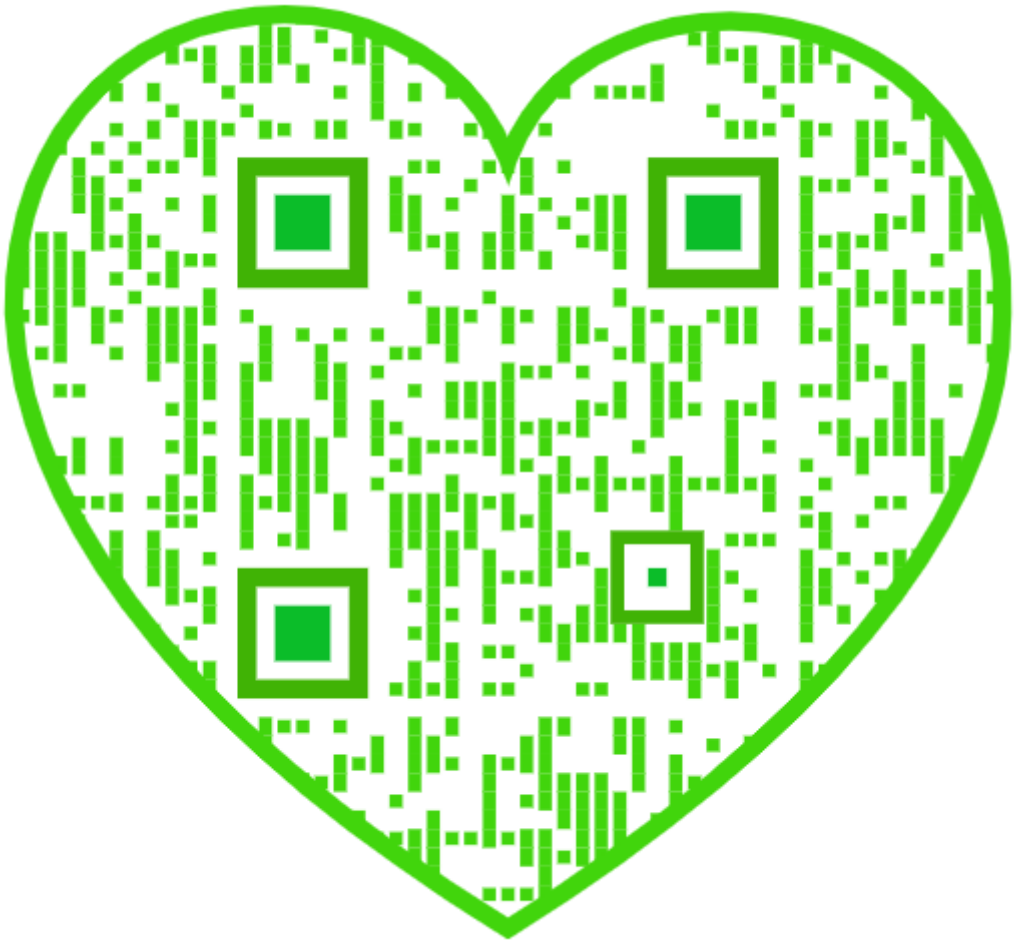

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The Naval Builder and Mathematician

PRACTICAL
MASONRY, BRICKLAYING,
AND
PLASTERING,

BOTH PLAIN AND ORNAMENTAL;

CONTAINING A NEW AND COMPLETE

SYSTEM OF LINES FOR STONE-CUTTING;

FOR THE USE OF WORKMEN;

WITH

AN AMPLE DETAIL OF THE THEORY AND PRACTICE OF CONSTRUCTING

ARCHES, DOMES, GROINS, NICHES, STAIRS, COLUMNS, &c.

BOND, FOUNDATIONS, WALLS, BRIDGES, TUNNELS, LIGHT-HOUSES, &c.

OVENS, FURNACES, &c.

THE FORMATION OF MORTARS AND CEMENTS;

INCLUDING, ALSO,

PRACTICAL TREATISES ON

SLATING, PLUMBING, GLAZING, &c. &c.

AND A FULL DESCRIPTION OF

THE VARIOUS MATERIALS EMPLOYED IN ALL THESE ARTS,

ILLUSTRATED BY NUMEROUS ENGRAVINGS, BY ARTISTS OF FIRST-RATE TALENT

LONDON:

THOMAS KELLY, PATERNOSTER ROW.

MDCCCXLI.

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PREFACE.

IN submitting the present Volume to the Public, we have to offer our grateful acknowledgments for the very favourable reception which the previous work on Carpentry and Joinery* has met with, and we feel much gratified in having been, in an eminent degree, successful in our endeavours to unfold and elucidate the scientific Principles and Practical Application of those Arts which have the object of employing Wood in the construction of Buildings: we now proceed to develope, in a similar manner, the *scientific Principles* and *Practice* of the Arts of Construction, using other materials, and particularly the important Arts of MASONRY and BRICKLAYING, and also the ORNAMENTAL ART of PLASTERING.

Our plan consists in separately treating the Arts of Construction, and elucidating them by grouping together those principal branches which have a natural relation to each other, and which require similar operations, and in which a workman in the one always has an advantage in knowing the principles of the others: and we are the more powerfully encouraged to proceed in it, by the knowledge that this plan is as *new* as it will be found *useful*, and we trust the Work itself will bear the palm, as well for *originality* and *beauty*, as for its *practical utility*.

The nature of our Work will be more fully understood from the following short sketch of its plan. First, we begin with a Treatise on Masonry, in which is given a complete System of Lines for *Stone Cutting*, in all its branches; as for instance, Arches, Niches, Domes, Plain and Gothic Groins, Mouldings, &c. Next we treat of the qualities of Building Stones, the nature and composition of

* The PRACTICAL CARPENTRY, JOINERY, AND CABINET MAKING; being a new and complete SYSTEM OF LINES, for the Use of Workmen; founded on accurate Geometrical and Mechanical Principles, with their application in CARPENTRY,—to Roofs, Domes, Centring, &c.; in JOINERY,—to Stairs, Hand-rails, Soffits, Niches, &c.; and in CABINET-MAKING, to Furniture, both Plain and Ornamental, fully and clearly explained.

This useful and scientific Work is completed in Thirty Numbers, Quarto, Price One Shilling each, or in Six Parts at Five Shillings each, containing Ninety Plates, and upwards of Two Hundred Diagrams, executed by Artists of the first-rate Talent. Printed for T. KELLY, price only 30*s.* in boards.

Mortars and *Cements*, and the principles of constructing Foundations, Walls, Bridges, Domes, Tunnels, Light-houses, &c.

Secondly, a Treatise on Bricklaying is introduced, showing the nature and qualities of Bricks, Tiles, &c. The Theory of Brick-bond and the construction of Arches, Groins, &c.; also the best methods of building Ovens, Furnaces, and Fire-places in general, &c.

Thirdly, a Treatise on Plastering, describing the composition of the materials, and their application in both Plain and Ornamental work, with specimens of Ornaments, in the various styles that have been adopted in that department at various periods.

Fourthly, of Slating, in which the various qualities of Slates are fully explained, and also the most perfect method of applying them as a covering for buildings.

Fifthly, of Plumbing, Painting, and Glazing, with a full description of the qualities of the materials, and the most approved methods of applying them: the whole forming a valuable mass of practical information peculiarly calculated to direct and assist the workmen in all these branches of the Building Art.

A Glossary of the peculiar Technical Terms applicable to each Department, is placed at the close of each division, in which an explanation is given of those objects which require it, and references to where they are treated of in the body of the work, by which means a greater facility will be obtained in consulting the Work.

The examples in the Plates are engraved in the best style, and are chiefly selected from the most approved works, already executed by the following distinguished Architects and Civil Engineers, viz. Messrs. Wyattville, Soane, Rennie, Telford, Brunel, Perronet, &c. &c., as we are persuaded that such designs will be found superior to any of our own. Our sole object and endeavours in the prosecution of these Works, have been to combine *Theory* with actual *Practice*, and to render both familiar and easy.

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The Publisher respectfully recommends to each Subscriber the following highly useful and necessary Addenda:—

THE PRACTICAL BUILDER'S PERPETUAL PRICE-BOOK;

Being a Sequel to "THE NEW PRACTICAL MASONRY AND CARPENTRY," elucidating the Principles of correctly ascertaining the average Value of the different Artificer's Works employed in Building; with the particular Customs of Measuring and Valuing in the various parts of the United Kingdom; comprehending, also, the Substance of every Clause in the Building Act. Intended as a Key to, or Illustration of, these Works, and will be found highly useful to the Gentleman, the Surveyor, and the Architect, as well as to all Persons anywise concerned in the Art of Building.

The Addenda is completed in Eleven *Numbers or* Two *Parts, in Quarto, illustrated with suitable Plates. It is also printed separately, in Octavo size, for the convenience of the Practical Builder, Surveyor, &c., price* Eight Shillings, *sewed.*

PRACTICAL

MASONRY, BRICKLAYING, &c.

BOOK I.

MASONRY.

INTRODUCTION.

Art. 1. MASONRY, practically considered, is the art of shaping and uniting Stones for the various purposes of Building. It, therefore, includes the cutting or hewing of stones into the particular forms required, and the union of them by level and perpendicular joints, connected by the aid of cement, or by iron cramps and lead. The operations of Masonry require much practical dexterity, with some skill in Geometry and Mechanics.

In treating on this subject, it will be necessary to divide it into several branches; but first, we may notice that, though necessity was its parent, nevertheless the fluctuations of this Art have marked the rise and fall of the Empires.

2. In Egypt, Greece, and Italy, among the greater works of masonry, are included some of almost incredible magnitude, formed of materials of the most imperishable nature. These countries seem to have been favoured with every thing which could contribute to their being eternized; for they abounded in the finest granites, porphyries, and marbles, which rendered their structures magnificent, independently of their size, or of peculiar contrivance in arrangement.

3. The older specimens of masonry of Britain, in point of geometrical skill and mechanical arrangement, are inferior to none: the magnificent structure at Cambridge, called King's College Chapel, is the most celebrated, and was justly styled by Lord Orford, "a work that alone will be sufficient to ennoble any age;" and it has, from time to time, received the homage of those who are best qualified to appreciate its merits. It is to be regretted, however, that in it, as in most of the old works in this country, too little regard was given to the selection of durable materials.

Modern masonry is chiefly directed to somewhat different objects; Bridges, Docks, Lighthouses, &c., works requiring an equal degree of skill, and if not productive of equal magnificence are infinitely superior in utility.

CHAPTER I.

OF THE DESCRIPTION OF ARCHES.

4. Arches are of various kinds, and, generally, receive their names from the curve which is formed by the intrados or soffit line. Thus we have circular arches, elliptical arches, and parabolic arches; when the intrados is a circle, an ellipse, or a parabola. Sometimes they receive their names from the style of architecture, as Gothic Arches, Persian Arches, &c. and some arches have particular names, as a segment of a circular arch is called a Scheme Arch, &c. The joints of the stones in an arch are generally made perpendicular to the curve of the intrados or soffit line.

5. To describe a Parabolic Arch, the span and height of the arch being given.

Method 1.—*Plate* 1, *Figures* 1 and 2.—Let AB be the span: bisect AB in the point C, and draw CD perpendicular to AB. Make CD equal to the height of the arch. Produce CD to E; making DE equal DC, join EA, EB. Divide EA into any number of equal parts, A1, A2, A3, &c.; and, E B into the equal parts E1, E2, E3, &c. Join the corresponding points 1, 1; 2, 2; 3, 3; &c., and the intersections of the several lines will form the parabola required.

Figure 1 is adapted to a segment, where the rise of the arch is considerable. *Fig.* 2 is adapted to the head of an aperture, where the radius of curvature of the arch is very great, or where the deflection of the curve from a straight line is but small.

6. *Method* 2.—*Fig.* 3.—AB and CD being as before, draw DE parallel to AB, and AE parallel to CD. Divide AC into any number of equal parts, and AE into the same number. From the points 1, 2, 3, &c., in AE, draw lines to D, intersecting perpendiculars to A, drawn from the points 1, 2, 3, &c., in AC. Through the points of intersection draw the curve AD. In the same manner draw the curve BD.

7. To determine the joints of the arch-stones, or to draw a straight line perpendicular to the curve from a given point *h*, (*fig.* 3,) as a joint.

In the curve take any other point, as B, at pleasure, and join B*h*. Bisect B*h* in *e*, and draw *e g* perpendicular to AB, intersecting the curve in the intermediate point *f*. Make *f g* equal to *f e*; join *h g*, and draw *h i* perpendicular to *h g*; then *h i* will be the joint required.

8. Or, draw *u h* parallel to AB, to meet DC in *a*; and make D*b* equal to D*a*; then join *h b*, and draw *h i* perpendicular to *h b*, and it is the joint. *Figure* 1 and 3. The same methods apply to *figure* 2.

A Practical Method of describing the Curve of an Elliptical Arch, from centres, and of drawing the joints.

9. Let AB (*figure* 4,) be the springing-line. Bisect AB in C, and draw CD perpendicular to AB, and make CD equal to the height or rise of the arch. Draw DE and AE, respectively parallel to AB and CD. Divide AC and AE each into three equal parts. Produce DC to *g*, and make C*g* equal to CD. Draw lines from the points of division in AE to the point D, to intersect other lines in *ef*, drawn from *g* through the points of division in AC; then, *e* and *f* will be points in the curve.

Bisect *f*D by a perpendicular, meeting D*g* produced in *h*, and join *hf*, intersecting AC in *k*. Bisect *ef* by a perpendicular, meeting *fh* in *i*. Draw *iq* parallel to AB. From *i*, with the radius *if*, describe the arc *fq*. Join *q*A, and produce *q*A to meet the arc *fq*: join the point of meeting, and the point *i* intersecting AB in *l*.

From *h*, with the radius *h*D, describe an arc D*f*; from *i*, with the radius *if*, describe an arc *fe*; and from *l*, with the radius *le*, describe the arc *e*A.

By transferring the places of the centres to the other side, the half, DB, of the semi-elliptic arc, ADB, may be described.

To draw a Tangent to a Semi-elliptic Arch, the axis-major being horizontal.

10. With the radius AC, (*figure* 5,) and D as a centre, cross AB in the points *u*, *v*, called the focii. Let *s* be a point in the curve: join *su* and *sv*. Draw *st*, bisecting the angle *usv*, and *st* will be the joint required. In the same manner any other joint, *qr*, will be found.

Or, by finding the position of the centres, and that of the lines for describing the curve, as in *fig.* 4, the joints may be drawn, as *qr* from *k*, *st* from *i*.

Figure 6 is a semi-circular arch, with the joints marked out.

Figure 7 a semi-elliptic arch, with the joints also marked out, and the centres for drawing them as before.

The Cyclograph.

11. For drawing arcs of circles, the Cyclograph is a most useful instrument, and may also be applied, in various cases, in drawing mouldings and flat curves, for the arches of Bridges, &c. *Figure* 1, of the *plate* II, represents the instrument, which is used by inserting points, as at A and C, at the springing of the arch, and adjusting the point of the pin or pencil, which is inserted in a tube, at B, to the height of the arch or curve, then fixing the joint by means of one of the larger screws to the right-hand side of the pencil.

Figure 1, No. 1, is a view of the instrument turned upon its edge, showing the tube and pencil fixed in the joint.

Figure 2, exhibits the legs without the brass-work.

Figure 3, No. 1, the brass-work, with the tube in the joint. No. 2, is a side view of *figure* 3, No. 1.

Figure 4, No. 2, exhibits the joint when the pieces are separated. No. 1, and No. 3, sections of *figure* 4, and No. 2.

Figure 5, the upper brass-plate, with a circular slit in it for the screw, which fixes the leg to move in, when the angle of the instrument is altered to adjust it, and it is by tightening the screws passing through the slit in the plate that the instrument is fixed.

Figure 6 is a section of the joint and tube to a larger scale, with a steel drawing-pen inserted instead of a pencil; it is fastened by means of a screw at the side of a tube. *Figure* 7 and 8 represent the screws.

CHAPTER II.

STONE-CUTTING.

12. Stone-cutting may be equally well done by various methods; the most certain consists in forming as many plane surfaces to the stone as may be necessary, in such manner that these surfaces may include the intended form, with the least waste of stone, or in the most convenient way for applying the moulds. Upon the plane surfaces thus prepared, the proper moulds are to be applied, and the stone worked to them. It will generally happen, that the bed of the stone will be one of the first plane surfaces, and the arrangement should always be made, so that there may be as little re-working as possible.

13. But, before we proceed to explain methods of forming stones to the particular shapes required for arches, vaults, &c., it may be remarked, that the young mason should be extremely careful to avoid making the beds of stones concave or hollow. For, if this be done in any case where the stones have to bear much pressure, they will flush, or break off in flakes at the joints and entirely disfigure the work. It is better that they should be slightly convex. In the construction of piers and columns, where perfectness of form is at least as much regarded as strength, this maxim should be carefully attended to. Nothing can be more offensive to the eye than a flushed joint, since it not only deforms, but also gives the idea of want of strength.

14. To form a perfectly Plane Surface, (see *fig.* 1, *plate* III,) the stone-cutter should commence by making a narrow part of it straight, with a chisel or point, along close to one edge, AB, of the stone; this narrow portion, formed to coincide with a rule or straight-edge, is called a *draught*. Another draught, AC, should be made along another edge, from one of the extremities, as A, of the first; and then a third draught, BC, being made in a diagonal direc-

tion, so as to meet the other two, and form a triangle; the three draughts will be all in one plane. Run a fourth draught, AD, in the direction of the other diagonal from the point A, in which the first two meet, and at the crossing to coincide with the first diagonal draught at E; and then reduce the intermediate parts between the draughts, so that the whole of the surface may coincide with the straight-edge, or be in a plane with the draughts.

Sometimes two other draughts are formed along the edges, BD and DC. It enables the workman to reduce the surface to a plane, with less risk of breaking the edge of the stone within the parts required perfect; and also to examine its accuracy by means of two parallel sticks placed along the opposite draughts, by which the smallest degree of winding can be detected.

15. To form a regularly Winding Surface, let draughts be formed along the edges in one plane, as for forming a plane surface, and from these draughts work the other sides so as to be square to the draught-lines; then set off A*a* (*fig.* 2,) on the arris equal to the quantity of winding, and draw *a*B and *a*C for the draught-lines.

If the lines *b e*, *c f*, *d g*, be drawn parallel to A*a*, and *e h*, *f i*, *g k*, parallel to AC. The draughts being cut at these lines, so that the straight-edge applies from *b* to *h*, *c* to *i*, and from *d* to *k*, and the surface be reduced so that a straight-edge applied parallel to the plane, A*a*B, may every where coincide with the surface, and also with the cross-draughts, then the surface will be of the form required.

16. If the side CD of the stone be shorter than AB, then the line *a*B (*fig.* 3,) must be divided into equal parts, and the lines *b e*, *e f*, *d g*, drawn parallel to A*a*; next divide the line CD into the same number of equal parts in *h*, *i*, *k*, and join *e h*, *f i*, *g k*, instead of drawing them parallel to AC.

The draughts being sunk till the straight-edge applies from *b* to *h*, *e* to *i*, &c., and then the surface finished, so that the straight-edge will apply in a direction parallel to the plane A*a*B, it will be of the required form.

17. *Of the Angles formed by Plane Surfaces.*—The angle made by two planes, which meet one another in an arris, is measured or ascertained by applying a bevel in a plane perpendicular to the arris; and if two lines be drawn at right angles to that arris, the one in the one plane, and the other in the other, the bevel being applied so that its legs are on the lines square from the arris, it will be set to the angle formed by the planes. This may be illustrated by drawing two lines, AB and CD, upon a piece of paste-board, at right angles to one another, crossing at the point E, and let the paste-board be cut half through, according to the line CD, so that it may turn upon that line as a joint, then to whatever angle AEB, (*fig.* 4,) the parts may be turned, the lines EA and EB will be always in the same plane. Also, a line FB, drawn from any point B, in the line EB, to any point F, in the line EA, will be always in the same plane. From this self-evident property of planes, it is easy to determine the angle formed by any two planes, when two plans, or one plan and the section or developement of the surfaces, are given.

18. Let ACB (*fig.* 5,) be the plan of part of a pyramid, and CD the elevation of the arris, or line formed by the meeting of the planes in respect to the line CE; CE being the line corresponding to the place of the arris upon the plan.

Draw DE perpendicular to DC, cutting CE in the point E, and through E draw AB perpendicular to CE. With the radius ED and centre E, cross CE in F; and join AF and BF, then the angle AFB is the angle formed by the planes of the pyramid. In this manner the angles formed by any plane surfaces may be found from drawings.

Of the Construction of a Semi-circular Right Arch.

19. Let ABCD (*fig.* 4, *plate* IV,) be the plan of the arch. Divide the opening into two equal parts by the perpendicular EF; from E, with a radius equal half the span of the arch, describe the semi-circle AFB, which is the intrados; and, from the same point E, with the radius of the extrados, or back of the arch, describe the semi-circle GHI. Divide the arch GHI, of the extrados, into five equal parts, and draw the lines *k o*, *l p*, *m q*, *n r*, to the centre E, for the joints, which will form the heads of the arch-stones; the arch-stones being all of the same form, they may be executed without making a mould for each stone, by having the head of the arch-stone and thickness of the wall only, in the following manner:

Choose a stone of sufficient length to answer for the thickness of the wall, and of breadth and depth proper for the other dimensions. Reduce the side intended for the intrados to a plane surface, on which draw the two parallel lines *a b*, *c d*, (*fig.* 1,) distant from each other the space between the joints of the intrados; then square one end, as, *a c* to *a b c d*, and parallel to *a c* draw *b d*, at a distance equal to the thickness of the wall. Square the other end of the stone, and on the head apply the mould *p q m l*, (*fig.* 4,) so that its extremities *p q* may coincide with *c a*, (*fig.* 1,) when applied to one head, and with *b d* when applied to the other; then hollow out the intrados, and cut the joints or beds according to the traces, as exhibited at *figure* 2.

Figure 3 exhibits a stone entirely finished, and all the others are formed after the same manner; but, instead of forming the heads on the stones themselves, a bevel, such as shewn in *fig.* 4, *k o* A, may be used with advantage.

The upper part of *fig.* 4 represents an arch-stone, accompanied with the moulds of each side, which will explain the application more particularly; and the middle part of *figure* 4 shows the arch complete, with all the stones supporting one another.

Of the Forms produced by the Intersection of Arches.

20. Whatever may be the form of an arch, the figure, which will be produced by a plane cutting it in an oblique direction, may be determined by means of the method of ordinates, which we propose to describe in this place, in order that the mason may know how the curves of an arch may, in any case, be derived from one another

Let MFL (*fig.* 6, *plate* III,) be the section of an arch, and BADC its plan, and let it be cut by a plane perpendicular to the plan, and in any direction CA, then the form of the arch, as shown on the surface of the section, may be found thus: Take any number of points, as, *f, e, d,* in the curve, and from each point draw a line parallel to the direction of the arch to meet the line of section CA, as in the points 6, 5, 4. From each of these points raise a line perpendicular to CA; and on these perpendiculars set off from the line CA, the height of the corresponding points in the arch above the springing-line ML. As, make EG equal to NF; 4 *k* equal *g d*, &c.; and, through the points G, K, *i*, *h*, C, draw a curve, which is the form of half the arch required, and the other half will be of the same figure.

21. The line of intersection of two arches is determined in the same manner, when they are formed so that the intersection is in a plane: and, to make the intersection in a plane, let BD (*fig.* 6,) be the line of intersection, and from each of the points 1, 2, 3, in this line draw a line in the direction, or parallel to the sides, of each arch; and make the corresponding points, *a, b, c,* in these arches of the same height above their respective springing-lines.

The whole of the figure shows the plan and sections of a plain groin, with the joints of the stones inserted in the plan.

The Elliptical Arch, with Splayed Jambs.

22. To find the angles of the joints formed by the front and intrados of an Elliptical Arch, erected on splayed jambs.

Figure 1, on *plate* V, is the plan of the Imposts, or Jambs.

Figure 2, the Elevation.

The plan of the impost ABCDE is the first bed; *f g h i k*, the second; *l m n o p*, the third; *q r s t u*, the fourth; *v w x y z*, the fifth: The other beds are the same in reverse order. The breadth of all these beds is the same as that of the arch itself. The lengths *h* K, *n* P, *s* U, *x* Z, of the front lines of the moulds of the beds are respectively equal to the lines HF, NL, SQ, XV, on the face of the arch. And also, *h g*, *n m*, *s r*, *x w*, on the fronts of the moulds equal to the corresponding distances HG, NM, SR, XW, on the face of the arch. The distances *k f*, *p l*, *u q*, *z v*, are each equal to the perpendicular part AE, of the impost.

To find the Joints of an Oblique Arch in Masonry.

23. Let ABC (*Plate* VI, *fig.* 1,) be the *intrados*, and DEF be the *extrados*, of the arch. Draw DK, AL, CM, FN, perpendicular to the base DF, of the arch. Make the angle DFG equal to the angle which the wall makes with the jambs of the arch, and draw KN, at a distance from GF, equal to the thickness of the wall; then the plan of the wall is represented by GFNK; the abutment on one side, or springing base, is represented by GHLK, and that on the other side by FIMN. Let J be the centre of the given arch.

Divide ABC, the intrados of the arch, into as many equal parts as the arch-stones are in number. Through the points 1, 2, 3, &c., draw lines 1 *q*, 2 *r*, 3 *s*, &c., cutting the one side KN of the wall at *q*, *r*, *s*, &c., and the other side at *n*, *o*, *p*, &c.

In *figure* 2, draw the straight line AB, and make AB equal to the length of the arch ABC, and let A *g*, *g h*, *h i*, be equal to the distances, 1, 2, 3, &c., on the arc ABC. Draw the perpendiculars ACE, *g k n*, *h l o*, &c. Make AC equal to AH, *figure* 1; *g k* equal to *k n*, *figure* 1; *h l* to *l o*, *figure* 1; *i m* equal to *m p*, *figure* 1; and so on: then through the points C, *k*, *l*, *m*, &c., to D draw the curve line CD. Likewise make AE, *g n*, *h o*, *i p*, &c., respectively equal to AL, *k q*, *m s*, &c., (*fig.* 1,); then, through all the points E, *n*, *o*, *p*, &c., to F, draw the curve EF, which will complete the whole developement of the soffit of the arch.

The parts C *k n* E, *k l o n*, *l m p o*, &c., are the heads, or exact forms, of the ends of the stones of the arch, and therefore the moulds of the ends of the arch-stones must be made to correspond to these figures.

To find the bevels of the joints of the stones.—Let *q*, *s*, *u*, (*fig.* 1,) be the points of division on the line of the intrados, next to the crown of the arch.

From the centre J, and through the points *q*, *s*, *u*, &c., draw the lines J *r*, J *t*, J *v*, &c., then *q r*, *s t*, *u v*, &c., will represent the joints of the arch. From the points *q*, *s*, *u*, &c., draw *q a*, *s d*, *u g*, &c., parallel to AH, cutting GF in the points *a*, *d*, *g*, &c.; and, from the points *r*, *t*, *v*, &c., draw *r e*, *t f*, *v i*, &c., parallel to AH, cutting GF in the points *e*, *f*, *i*, &c. Draw *b e*, *c f*, *h i*, &c., parallel to DF.

Then, to find the bed of the stone answering to the joint *q r*, draw the straight line *a b c*, No. 1, and make *a b* equal to *b a*, *figure* 1. Draw *a e* perpendicular to *a c*, and make *a e* equal to *q r*, *figure* 1; and make *a e*, No. 1, equal to GK or HI, &c. In No. 1, draw *c d* parallel to *b e*, and *e d* parallel to *a c*; then will the figure be formed of the bed of the stone.

In the same manner we may form No. 2, to the joint *s t*; and No. 3, to the joint *u v*; and so on.

Nos. 1, 2, 3, 4, 5, &c., are the forms of the moulds for the beds of the right-hand arch-stones; and Nos. 1, 2, 3, &c., reversed on the right-hand, are the moulds for the beds of the arch-stones on the left-hand: viz. No. 1, and No. 1, are the two bed-moulds next to, and on each side of, the crown; No. 2, and No. 2, are the second equi-distant bed-moulds from the crown.

In working the stones, the beds ought to be numbered the same as the moulds, in order that the arch-stones may be readily applied together.

The stone-cutters usually first work one of the beds, and mark the form of the mould upon the bed of the stone; and so cut the rest from it.

To find the Joints of an Oblique Circular Arch.

24. Let ABNO (*figure* 1, *plate* VII,) be the face of an oblique arch, of which *r s m n* is the plan; A M *r m*, O Q *s n*, the imposts; *r m* and *s n* being the lines of the jambs.

Suppose the obliquity of the arch to be given, with the number of stones requisite for its construction, the figure of the stones may be obtained by the following construction :—

Find the centre C, of the span *r s*, which join with the points of division in the arch, by the straight lines CB, CN, &c. At the point C, in *r s*, make the angle *r*CD equal to the given obliquity; in CD take any point, as P, and from P, draw PE, meeting *r*C perpendicularly in E: Upon EC describe the semi-circle E*a b c* C, cutting the joints produced in the points *a, b, c*: with the distances E*a*, E*b*, E*c*, describe arcs meeting EC in the points *a', b', c'*; join P*a'*, P*b'*, and P*c'*, then will P*a' r*, P*b' r*, and P*c' r*, be the angles of the faces of the stones to which they are referred.

Again, to find the angle of the bed: upon PC describe the semi-circle P*a'' b'' c''* C; and, from C, with the distances C*a*, C*b*, C*c*, cut the semi-circle in *a'' b'' c''*; join P*a''*, P*b''*, and P*c''*, then PC*a''*, PC*b''*, and PC*c''*, will be the angles of the bed.

25. In this case the angles may be determined by Calculation.—In the triangle PCE we have given the angle at C equal to the obliquity, and the side CP any magnitude at pleasure; hence the sides PE and EC can be found: then, in the triangle EC*a*, we have given the angle at C, and the side EC to find E*a* equal to E*a'*; lastly, in the triangle EP*a'* we have given the sides PE, E*a'*, to find the angle P*a'*E, which is the angle made by the face of the stone and its bed.

The general formula is cot. req. ang. = cot. obliquity × sin. $\frac{180° \times m}{n}$, where n is the number of stones in the arch, and m any multiplier in the natural series, 1, 2, 3, &c.

The angle formed by two contiguous boundaries of the bed is found exactly as the last.

The formula is cos. reg. ang. = cos. obliquity × cos. $\frac{180° \times m}{n}$.

As a particular example, suppose the obliquity to be 73°, and the number of stones 11, the respective angles will be exhibited in the following Table:—

	Divisions of the Arch.	Face Angles.	Bed Angles.
1	16° „ 21′ „ 49$\frac{1}{11}$″	85 „ 4′ „ 37″	73° „ 42′ „ 29″
2	32 „ 43 „ 38$\frac{2}{11}$	80 „ 36 „ 52	75 „ 45 „ 41
3	49 „ 5 „ 27$\frac{3}{11}$	76 „ 59 „ 23	78 „ 57 „ 42
4	65 „ 27 „ 16$\frac{4}{11}$	74 „ 27 „ 31	83 „ 1 „ 25
5	81 „ 49 „ 5$\frac{5}{11}$	73 „ 9 „ 46	87 „ 36 „ 55

The angles for the remaining divisions being the supplements to those in the table, it is unnecessary to give them here.

To apply the formulæ to a numerical Example, we will take the first division in the table—

Formula first:
Cot. 73° ..... Log. —1.485339
Sin. 16° „ 21′ „ 49$\frac{1}{11}$″ —— 9.449836
Cot. 85 „ 4 „ 37 —— 8.935165

Formula second:
Cot. 73° ..... Log. —1.465935
Cos. 16° „ 21′ „ 49$\frac{1}{11}$″ —— 9.982012
Cos. 73 „ 42 „ 29 —— 9.447977

One of the stones, when finished, will appear as in *figure* 2; where PDE and QRC are the two angles requisite in its construction; PDE being the angle of the face, and QRC the angle of the bed.

Oblique Arch.

26. Let ABCD, (*fig.* 1, *plate* VIII,) be the plan, parallel to which draw DC, (*fig.* 2,) on which, as a diameter, describe the semi-circle DFC; divide the arc DFC into as many equal parts as the proposed number of stones to be in the arch, which, in this instance, is five. Draw the joints of the face tending to the centre E; draw also the horizontals and perpendiculars of the intrados marked by dotted lines in the figure.

To form the arch-stones.—The plan of the jamb HBCL, enlarged to the line KI, will make a bed for a stone for the springing-course, and work the four adjacent sides each so as to be at right angles to HIKL. Apply the mould MNOP (*fig.* 2,) to the two ends, so that MN may coincide with KL and HI; the stone being thus gauged, make the upper and under beds parallel to each other. The stone, being now brought to the square, as seen at *fig.* 3, apply the mould CNORQC, (*fig.* 2,) so that NO may coincide with *b c*, and CN with *a b*. Draw *d g*, *e h*, and *a p*, parallel to the arris *k l*, then work off the joint *d g h e* and the intrados *a e h p a*, and the *first arch-stone* will be finished.

Having made the upper surface of the second stone, as in *fig.* 4, apply to it the mould STUV, (*fig.* 1,) forming the parallelogram *a b c d*, (*fig.* 4.) Then work off the four adjacent sides to a right angle with it, also gauge the stone to its depth, and work off the lower horizontal surface; apply the mould of the head to the ends of the stone, as in working the first arch-stone, and draw the lines parallel to the arris *a d*, then work the joints and the intrados as before, and the stone will be finished.

The key-stone, exhibited in *figure* 5, is wrought in the same manner, and the whole arch, as completed, is represented by *figure* 6.

A Semi-circular Arched Passage, between Two Semi-circular Arched Vaults.

27. *To form the curve of intersection, and cut the stones for this arch.*—Let AB (*pl.* IX.) be the thickness of the wall through which the passage is to be made, BC and A*t* the two semi-circular arches; EL the opening of the passage; by which its arch GH*c* is described. Divide the arch into any number of parts, at pleasure, and through the points of division draw the lines H*t*, K*p*, *w*N, which, with the semi-circular arches, will form mixt angles, that serve to give the heads of the stones the proper projection, for intersecting the semi-circular vaults.

To mark in the plan, the meeting of the passage with the semi-circular vaults, let fall the perpendiculars CO, SI, QR, &c., which, by their intersecting or meeting the lines RT, IV, OF, &c., will give the points R, I, O, &c., through which trace the curves POR and EFL.

To trace one of the first stones; square the bed and one side of a stone, take the thickness of the wall AB, which set off on the arris of the stone, and, at each end of this line draw two others on the bed, square to the arris; and with a bevel take the mixt angle ZAN, then dress the two heads by this bevel, applied square to the bed; on the under bed set off G *b*, and trace a line parallel to the arris, and on the side set off *b w*, then work the soffit by the curve G *w*, and cut the joints square to the curve of the soffit; that is, the joint of the semi-circular vault by the mixt angle A N *r*, and that of the passage by the bevel M *w u*. Proceed with the other stones in the same manner, excepting that the bevel *n* QC is used to cut the sweep of the second stones, and the bevel *s p v* for the key. The rest is so plain as to require no explanation.

An Archway revealed and splayed, and the Splay arched with a Segment, in order to give room for Gates to open when they are made to the height of the front Arch.

28. The elevation (*pl.* X, *figure* 1,) will give a correct idea of an arch of this kind. A is the impost, BB the reveal, C the splayed recess. Let ABDC, (*figure* 2,) be the plan, A *e* the depth of the impost, *e f g* the reveal, *g* C the splay.

Describe the arch of the gate-head A′E B′, and that of the reveal *a′ e′ b*; and, at the extremities C and D of the splay, draw the perpendiculars CF′ and DG′, in which find the points F and G in the following manner:

Describe the arch of the splay I′ K′, (*fig.* 3,) make I′ L′ equal to *g* C, (*fig.* 2.); perpendicular to I′ L′ draw L′ K′; make M′ F′ and N′ G′ each equal to L′ K′, and through the points F′ G trace the arc F′ G′, as flat as may be necessary for the gates to swing open.

The most complicated joint in this gate is OP, formed by the arc of the reveal and that of the splay. To draw the joint-mould for this: from the point *h*, (*fig.* 2,) draw *h* Q′ perpendicular to AB, meeting O′ P′ in Q′. Draw I′ S′ perpendicular to I′ L′, and Q′ S′ and P′ T′ parallel to I′ L′: join T′ S′ intersecting the arc in U′; draw U′ V′ parallel to P′ T′, meeting the joint-line O′ P′ in V′, and V′ is the point in which the stone will form an angle. Draw the line of the impost *a b*, and the reveal *b e d* (*fig.* 2.); draw U′ W′ perpendicular to I′ L′, make *h i*, on the splay of the jamb, equal to I′ W′, and draw *i k* parallel to AB. Make *k l* equal to O′ V′, *m n* equal to O′ P′, join *d l*, *l n*, and *a b e d l n* will be the form of the joint; and all the joints which are cut in this forked angle are found in the same manner.

For the mould of the second joint.—Make *m p* equal to XY, and join *d p*.

To cut one of the first stones.—With the head-mould, B′ O′ P′ I′, prepare an arch-stone, as No. 1, whose length is equal to *a m* on the plan; apply the mould of the plan, IA *e f g* CK, on the under-bed, and, on the upper-bed, the joint-mould, *z a b e d l n x*. On the soffit of No. 1, draw ab, to mark the thickness of the impost, and, on the rear or tail of the stone,

draw c*d*, representing N′P′ on the elevation. Then, to hollow out the concave surface of the reveal, with a curved bevel *b′ l′*, (*fig.* 3,) draw the curves e f, g h, No. 1. By the lines, b c, c*d*, d k, dress that side which will be terminated by k h, making use of the curved templet cut by *b′ l′*, (*fig.* 3,) which apply, from time to time, till the forked-joint is formed, and the whole of the superfluous stone being cut away, it will appear in the form of No. 2.

The second stone, No. 3, is traced in the same manner.

Of Spherical Vaults or Domes, and Niches.

29. The joints of a Spherical Vault, or Dome, are of two kinds; the horizontal ones are portions of conic surfaces, and the vertical joints are planes tending to the centre. *Figure* 1, *plate* XI, represents the plan and section of a spherical dome, with the joint-lines of the stones; and, where the number of rings of stone are more numerous the construction is the same, and the moulds are found in the same manner.

The first operation consists in dividing the plan and section into the proper number of stones, and drawing the joints; the points through which they pass being transferred from the plan to the section by the faint dotted lines shown in the figure.

The next operation is to find the moulds for the springing-course; the size of the stone is included in the lines 1-2-3-4 on the section; and, if the stone be worked as for a cylinder to be placed round the plan, so as to coincide with the joint-line *a c*, it will be prepared for applying the mould A-1-4-*b a*; and the line *k l*, (*fig.* 3,) of the upper-bed should be drawn by a mould cut to a circular arc of the radius *b p*, (*fig.* 1,) the arc of the under-bed is the same as the plan of the wall, and the concave surface may be worked from the under-bed to a bevel, having its leg curved to the same curvature as the dome.

The next stone (*fig.* 4,) is included in the lines, 5-6-7-8, of the section; and, in like manner, is to be worked as part of a cylinder, and the mould *a b*-8-12-*d* in the section being applied to its vertical joints, the boundaries of the conical and spherical surfaces will be found, and the angle *b a d* will be the bevel to work the spheric surface.

Lastly, the key-stone is included by the lines 9-10-11-12; and, work a square stone to the size 11-12, and thickness 9-12; then describe a circle to the diameter 11-12, on the upper surface, and to the diameter *d q*, on the lower surface; to these draughts work the conical surface forming the bed, as shown in *fig.* 5, and the concave surface to a mould *d* D *q*, which completes the set.

With foreign authors, it is usual to find the forms of flexible moulds for the beds, *c m l k*, and *h e f g*, we do not think them necessary; but as they are easily found, we describe the readiest and most accurate method of obtaining them. Take the radius of the dome CB, and centre C, (*fig.* 2,) and describe an arc *c h*; then, draw a line *b* C, cutting the arc in *a*; set off from *a*, on the arc on each side, the length of the arc *a c* on the plan, which will give the points *m*, *c*;

and, from C, draw lines through m and c; also, make $a\,b$ (*fig.* 2.) equal to $a\,b$ in the section, and from C describe an arc through b, then will $c\,h\,m\,l$ be the development of the bed. In like manner $h\,e\,f\,g$ is the development of the upper-bed, marked with letters corresponding to those of the parts whence the measures are taken in the plan and section.

30. *Spherical Niches* are constructed in the same manner; the niche being considered a portion of a dome, and is usually half a dome.

31. When a Dome has an elliptical base, the same method may be followed, but the division into arch-stones should be made so that the opposite stones may be exactly in corresponding parts of the curve of the plan; for then, four stones of each ring may be worked by the same moulds.

Of Ribbed Groin Vaults.

32. The simple groined vault, with ribs, is the most difficult to construct; for the ribs of the other kinds of Gothic vaults are all of the same curvature, and meet, at equal angles, on the pillars or corbels from whence they spring.

Let ABCD, (*fig.* 1, *plate* XII,) be the plan of the first division of a ribbed-groined ceiling; and *fig.* 2 the section through GH; *fig.* 3 the angle rib; *fig.* 4 the plan of the top of the corbel or capital on which the ribs meet; and *fig.* 5 the key-stone.

The conditions to be attended to in the construction, are, that the plan of the ribs must meet within a circle on the top of the capital or corbel; and, that the angle-ribs shall be traced to correspond with the body-ribs; to obtain these conditions, the plain part of the pannels of the ceiling must deviate a little from the true groin, but this is a less evil than any which can be taken to remedy it.

Imagine the angle-rib BI, (*fig.* 1,) to turn on the centre, B, till it be parallel to BA; then, if BE (*fig.* 3,) be the form of the body-ribs, BI will be that of the angle ones; and is traced from BE, in the manner shown by the lines.

The stones of the ribs are generally long enough to correspond with two stones of the pannels; but, in some cases, the stones of the pannel are made to bond into the rib, at every second or third stone of the rib; and the joints of the ribs are always strengthened by dowels, or plugs, two to each joint.

The plan of the key-stone is an octagon, (*fig.* 5,) and the under part is shown below, with the section between.

All the intersections are covered with roses, or bosses; these are now commonly modelled and cast in Roman cement; but in former ages they were carved in stone.

Of Raking Mouldings.

33. Raking Mouldings frequently occur in Masonry; hence we give the following designs, which will be sufficient to explain the method of forming them to mitre in a proper manner.

Figure 1, *plate* XIII, is a complete design of a cornice, having part of the ogee level, and part inclined, as happens in a building, with a pediment in the front: *a, b, c, d, e,* is the moulding at the angle of the break, or projection of the pediment, with this moulding given, we have to find the right section of the inclined ogee in the pediment. Let *a f* and *e* e be the two parallel lines which terminate the breadth of the raking or inclined moulding; and let *a k* and *e l* be the parallel lines terminating the breadth of the moulding which is level.

At a convenient place draw *p t* parallel to the edge *a k* of the level ogee; and in the given moulding, *a, b, c, d, e,* take any number of points, *b, c, d,* and draw *b g, c h, d i,* parallel to *a f,* or *e* e; also draw *a p, b q, c r, d s,* and *c t,* perpendicular to *a k,* or *e l,* meeting *p t* in the points *q, r, s*: also, at any convenient distance from *a f,* draw *p′ t′* parallel thereto, and transfer the distances *p q, q r, r s, s t,* to *p′q′, q′r′, r′s′,* and *s′t′,* and draw *p′* A, *q′*B, *r′* C, *s′* D, *t′* E, perpendiculars to *t′p′,* or *a f,* meeting the lines *a f, b g, c h, d i, e* e, in the points A, B, C, D, and E, and a curve, being drawn through these points, will be the right section of the raking-moulding.

To find the section through the mitre of the two inclined sides, where they meet at the top of the pediment, draw *t″p″* perpendicular to *t″* e, and transfer the distances *t s, s r, r q, q p,* to *t″ s″, s″r″, r″q″, q″p″.* Draw *s″*d, *r″* e, *q″*b, *p″*a, perpendicular to *t″p″,* also draw *f* a, *q* b, *h* c, *i* d, perpendicular to *t″* e. Then the curve through the points a b c d e will be the common section of the two raking-mouldings, as required.

Figure 2 is a *reverse ogee,* which is traced on the same principle as the ogee, *figure* 1.

CHAPTER II.

OF THE MATERIALS EMPLOYED IN MASONRY.

34. Building-stone is a dense coherent body of considerable hardness and durability, generally of a brittle nature, and it possesses these qualities in various degrees, according to the nature of the matter it is formed of, or the manner in which its parts are joined to one another. The texture of stones is either slaty or granulated, or it is of a mixed nature.

35. Building stones are generally composed of two or more of the chemical earths called silica, alumina, lime, and magnesia, with small quantities of some of the metals combined with acids, water, and sometimes with the fixed alkalies; some other chemical elements are sometimes found in building-stones, but not often in sufficient quantity to affect the nature of the stones.

36. Slaty stones consist of thin plates, or layers, cohering more or less strongly together; when the layers are of considerable size, and cohere so slightly that they may be easily sepa-

rated, the stones are called *Slates*. The layers are always nearly parallel to the quarry-beds of the stone, and they should always be horizontal, or as nearly so as possible, in a building, otherwise the action of the weather will cause them to separate, and fall off in flakes. Sandstones generally have a slaty texture, and the direction of the layers may often be discovered by their different shades of colour, when they will not readily separate; in others, the layers may be distinguished by the position of minute scales of shining mica, which always lie parallel to them. In most stones, the direction of the layers may be ascertained by the facility with which the stone yields to the tool in that direction, but a considerable degree of practice is necessary to acquire so nice a discrimination of resistance, and good workmen only attain it.

37. Among slaty stones those are the most durable in which the slaty structure is least distinct, and the texture uniform. When the parts do not perfectly cohere, they are soon injured by frost, and they are wholly unfit for places alternately wet and dry.

38. GRANULATED STONES consist of distinct concretions resembling grains, either all of the same, or of different minerals, cohering together. When the texture is uniform, and the grains or concretions are small, stones of this kind are always strong and durable, if the concretions themselves be so. Granulated stones are sometimes open and porous, but when they are uniformly so, they seldom suffer materially by frost, because their uniform porosity allows the expansive force of the congealing-water to be distributed in every direction.

39. Stones of a compound structure, that is, partly laminated and partly granular, have, more or less, of the characters of the two classes before described; for it may be observed, in coarse-grained granite, that the laminated structure of some of its parts, render it very liable to shiver away by the effect of the weather.

40. All the kinds of stone, in the quarry, are found divided by vertical or inclined seams, or joints, which are sometimes so close that they cannot be distinguished till the stones be wrought, but they often separate under the tool at such seams; and it is not safe to employ stone to resist any considerable cross-strains, on account of the difficulty of knowing where those seams are.

41. The qualities requisite for building-stones for bridges, or water-works, are, hardness, tenacity, and compactness, with the property of resisting the decomposing effects of water, and of the atmosphere. Besides, the strength necessary to support the weight in such buildings, they must also often have to resist the impetus of floating bodies, and particularly of large masses of ice. Those stones which are the hardest, are not precisely those which have the most tenacity or toughness, of this we have a familiar illustration in comparing common limestone and glass; the latter, though much harder, is far more easily broken than the former.

42. The causes that accelerate the decay and destruction of stone in buildings are nearly the same with those which occasion the destruction or wear of rocks on the surface of the globe; they may be classed into two kinds: those of decomposition, and those of disunion of parts. In the former, a chemical change is effected in the stone itself; in the latter, a mechanical division and separation of its parts.

43. Decomposition takes place, when the stone contains parts that are, more or less, soluble in water, or which enter into combination with the oxygen of the air or acids in water. Iron, in different states of oxydation, and in different proportions, enters into the composition of almost all stones, and is frequently an important agent in their decomposition. When stones contain pure iron, it rusts or oxydates, and expands so as to burst the parts asunder. The iron absorbing oxygen and carbonic acid from the air, the presence of moistures accelerates this kind of decomposition and it is always still further hastened by increase of temperature. According to the observations of Kirwan, stones, containing iron, which does not contain its full doze of oxygen, are of a black, a brown, or a bluish colour; and, in some instances, when united with clay and magnesian earth, they are of a gray or greenish gray; the former, as the iron draws oxygen from the air, changes to purple, red, orange, and, finally, pale yellow; the latter kind becomes, at first, blue, then purple, then red, &c. But stones, containing iron, combined with its full doze of oxygen, are generally very durable: such are red porphyry, jaspers, &c. Stones, containing manganese, lime, alumina, carbon, or bitumen, in particular states, are subject of decomposition, from the affinities of one or other of these bodies; but nothing very decisive is, or perhaps can be, known, respecting such changes, unless the component parts be determined with some certainty.

44. Disintegration is the separation of the parts of stones by mechanical action, the chief cause is, the congelation of water in the minute pores and fissures of stones, which bursts them open, or separates small parts according as the structure is slaty, or irregularly granulated. The south sides of buildings, in northern climates, are most subject to fail from this cause; for the surface is often thawed, and filled with wet, in the sunny part of the day, and frozen again at night. This repeated operation of freezing is also very injurious to sea-walls, the piers of bridges, and other works exposed alternately to water and frost.

45. *Granite* is a compound siliceous rock, which varies much in the proportion of its constituent parts, and its degrees of hardness; compared with most other rocks, granite may be considered as a durable building-stone; but those granites that contain much white felspar, and only a small portion of quartz, like the greater part of the granites of Cornwall and Devonshire, are liable to decomposition and disintegration much sooner than many of the Scotch granites, in which the quartz is more abundantly, and more equally disseminated, and the grain finer. In the selection of granite, in Cornwall and Devonshire, the preference is given to that which can be procured in the largest blocks, and worked with the greatest ease, and for common purposes, it may answer very well; but, for the piers and arches of bridges, the harder granite will be found much more durable, such as the Aberdeen now using for London Bridge. In Cornwall, many of the granite rocks are in a state of rapid disintegration and decay, the felspar in that granite contains a portion of potass, and to this its more rapid decomposition may be principally ascribed, hence the stones should be carefully selected. The Naval Hospital of Plymouth is built of Cornish or Devonshire granite, which appears to have

been selected with care, for it has been erected about seventy years, and exhibits no symptoms of decay, except some slight ones in the columns forming the colonnade in front of each building. Cornish granite was used for the Waterloo Bridge, and shows some tendency to fret away in the piers; the new London Bridge is of Aberdeen granite.

Kind of Granite.	Weight of a cubic foot.		Pressure it will bear with safety on a square foot.
Cornish Granite	166 lbs.	..	114,000 lbs.
Peterhead Do.	—	..	149,000
Aberdeen Blue Do.....	164	..	196,000

46. LIME-STONES are very different in external appearance; the most crystalline marble as well as chalk and calcareous sand-stone being composed of lime. Of marbles there are an almost infinite variety, indeed every variety of lime-stone that admits of a good polish is denominated marble. Though lime is, in a certain degree, soluble in water and carbonic acid, yet, in its most indurated state, as in crystalline marble, the action of the atmosphere produces little change in the course of many centuries; but, when exposed to the constant action of water, the decomposition is more rapid. Those marbles which are the most uniform in their texture, which possess the greatest degree of specific gravity and hardness, and which will receive the highest polish, are those which will prove the most durable. The common coloured, and the softer kinds, are very generally used for building-stones in all lime-stone districts; and the principal varieties are here described.

47. The *Portland* and *Bath stones* (called Roe stone) are lime-stones, and very extensively employed in architecture; they can be worked with great ease, and have a light and beautiful appearance, but are porous and possess no great durability, hence they should not be employed where there is much carved or ornamental work, for the fine chiselling is soon effaced by the action of the atmosphere; on the other hand, on account of the ease and cheapness with which they can be carved, they are much used by our English architects, who appear to have little regard for futurity.*

Portland as well as Bath Stone varies much in its quality; but we think greater attention was paid to its selection in the construction of St. Paul's Cathedral, than in many of the modern edifices built of this stone, though we have observed many stones in the upper part of the building mouldering away; yet, on the whole, it is less injured by the weather than Somerset-House. In buildings constructed of this stone, we may frequently observe some of the stones nearly black, and others presenting a white clean surface. The black stones are those which

* The Chapel of Henry VII. affords a lamentable proof of the inattention of the architect to the choice of the stone. All the beautiful ornamental work of the exterior had mouldered away in the comparatively short period of three hundred years; it has recently been cased with a new front of Bath stone, in which the carving has been faithfully copied, but, from the nature of the stone, we may predict that its duration will not be longer than that of the original. Probably the architect was limited by contract, which precluded the use of a more durable but more costly stone.

are most compact and durable, and preserve their coating of smoke; the white stones are decomposing and constantly presenting a fresh surface, as if they had been recently scraped. This effect is strikingly exhibited in the columns of Somerset-House.

48. Bath Stone, Ketton Stone, and Painswick Stone, are all varieties of the same kind of stone, procured at those different places, as well as from several others in their neighbourhood. The stone is so much softer than that from Portland, that it may be cut with a carpenter's saw, and it may be moulded and carved more in the manner of wood than of stone, nevertheless it is quite as durable as Portland stone, and fitted for similar works, excepting where strength or wear is required. The Painswick variety is perhaps the closest and best for London use, as it works with very little waste; the Ketton seems to be the most durable, but none of these varieties are hard enough for steps, stairs, or other works liable to wear, or requiring strength

49. The strength and weight of the different varieties of Limestone are as under—

Kinds of Lime-Stone.	Weight of a cubic foot.		Pressure it will bear with safety on a square foot.
White Statuary Marble	172½ lbs.	--	83,000 lbs.
Veined White Marble	170	--	174,000
Variegated Red Devonshire Marble	—	--	129,000
Portland Stone	132	--	30,000
Bath Stone	123½	--	17,000

50. Argillaceous Stones, or those which contain in their composition a considerable portion of clay, are generally found to contain also a large portion of iron. This metal appears to have a greater affinity for argil, or clay, than for any other earth; and is sometimes combined with argillaceous stones in the proportion of one-fourth of the whole mass. The iron is frequently in the state of black oxyde, and in this state rapidly combines with a larger portion of oxygen, when exposed to the atmosphere, and thus occasions the surface of the stone to swell and shiver away. Stones of this kind, in their native beds, some hundred feet under the surface, are so extremely hard that they resist the point of the pick, and can be removed only by blasting; yet, when the same stone is exposed for some months to the air, it becomes soft, and shivers into small pieces. It rarely happens that builders or engineers have sufficient mineralogical science to enable them to anticipate the changes which will be effected by air and moisture on the materials they select; and the loss which this ignorance has occasioned in the construction of many public works is well known.

51. The most important of the argillaceous stones is the common Whin-Stone, called *basalt* by geologists; this stone is found in many parts of England, and also in Scotland, where whole villages are built of it, even where sand-stone could have been easily procured, as in the neighbourhood of Kelso. Whin-stone, when broken, is generally of a blue colour, of close grain, and remarkably hard; in its natural beds it is in irregular masses; too clumsy, and too

hard for the finer works of masonry; the best for architectural purposes is found in loose blocks in the beds of rivers, and places of a like nature, where it has been long exposed to the weather, for some varieties of whin-stone decompose by exposure in the manner of other argillaceous stones, (*art.* 50.) and are said to become rotten. By exposure, a thin coating forms on the surface of whin-stone; and it is said to be more durable when the coat is frequently cleaned off. The more hard and durable kinds are valuable for road materials. Whin-stone, and indeed all argillaceous stones, attract moisture, and in consequence assume a darker colour in damp weather; when the atmosphere is damp, walls of this stone condense the vapour till it runs down in streams, hence it is not generally adapted for houses.

The weight of a cubic foot of whin-stone varies from 170 to 192 lbs.; and, according to experiment, it appears that 280,000 lbs. may be supported by a superficial foot with safety.

52. Of SAND-STONES there are two kinds, which are very common, viz. the *siliceous* and the *argillaceous*;—of these the siliceous is the best, and perhaps the most abundant.

Sand-stone is common to most counties of England, as well as Scotland. The quarries of siliceous sand-stone about the cities of Glasgow and Edinburgh afford very superior kinds, which contribute in no small degree to the elegance of the buildings in these places; the superiority, however, is in material only, as the taste with which some towns built of brick have been laid out and executed, is not inferior to that displayed by the architects of the north.

In the parish of Sproustone, near Kelso, is a sand-stone quarry, belonging to the Dowager Duchess of Roxburgh, of immense value. The stone is of a beautiful silver grey, which, when exposed to the weather, soon becomes of a smokey hue. It is remarkably fine grained, indeed, so fine, that it is unfit for the purpose of whetting an edged instrument. Most part of Kelso is built of it, as well as the whole of the bridges in its vicinity. Although not a hard stone, it is very durable, and the seam is so deep and long that stones of large dimensions can be procured from it.

There are also many other excellent beds of sand-stone in the course of the Tweed, but that which we have just mentioned is perhaps the best. A little farther up, on the lands of Dryburgh, the property of the Earl of Buchan, there is plenty of sand-stone; it is of a deep red colour, and much indented by cross scars and seams; it is not, therefore, so generally useful as some other at no great distance from it. In the body of this stone there are many small pieces of a softer texture, and a deeper red, that do much injury to it as a durable material. The celebrated statue of Sir William Wallace, the defender of Scottish liberty, is cut out of a mass of this stone; but the sculptor, Mr. John Smith, of Darnick, has shown his skill in selecting the piece which he has used, as it appears too hard to yield to the ravages of time and of weather.

On the banks of the Tiviot, in the parish of Roxburgh, there is a bed of sand-stone, of excellent quality, fit for almost any purpose to which it may be applied. This has been used to a great extent, by the proprietor, Sir George Douglas, of Springwood Park, but has not been

brought into general use. It is of a white yellow colour, and rises from the bed in masses sufficiently large for every purpose of masonry. In the old buildings, in the neighbourhood, there is a species of sand-stone of a beautiful yellow and uncommonly soft; but where the builders found it cannot now be ascertained, as no vestige of a seam remains wherein the stone is of such a deep and beautiful colour. Should such be discovered, it will be of immense value to the proprietor, from its beauty, which would bring plenty of purchasers: but we conclude that it is of a nature not adapted to resist the weather, and that, in process of time, by being exposed to wetness and drought, it becomes of that soft state we find it in among the ruins of old buildings. A little farther up, on the precipitous banks of the Tiviot, there are extensive beds of yellow sand-stone; but, from their situation, they cannot be wrought with success.

In Dumfriesshire are great quarries of sand-stone, both of a red and white colour, exceedingly good; the towns of Dumfries and Maxwelton are built chiefly of the red kind. The masses here are very small, and prevent the masons exhibiting their skill, to any great extent, in cutting figures, and other architectural ornaments.

If we mistake not, there are numerous and excellent beds of this stone about the town of Kirkcudbright, and the surrounding country: but that which is found abundantly in Ayrshire, on account of its white colour and durable nature, is to be preferred to any that we have yet mentioned, Sproustone only excepted.

The quarries in the other parts of Scotland, being nearly of the same nature with those already described, and this remark applying also to the quarries of sand-stone in England, we need not enter into farther notice of it; since its utility, as a building material, is very generally known.

A kind of argillaceous sand-stone is much used in London, for rough paving and steps, under the name of *Yorkshire Stone;* it is a very strong and durable stone, and wears well; but there is an objection to its use for internal work, owing to its absorbing damp rapidly, which renders it cold and uncomfortable for flooring.

53. The strength and the weight of a cubic foot of the different varieties of sand-stone are as under:—

Kinds of Sand-Stone	Weight of a cubic foot.	Pressure it will bear with safety on a square foot.
Dundee Stone	163 lbs.	119,000 lbs.
Bromley-fall Stone	157	109,000
Yorkshire Paving Stone	157	102,000
Craigleith Stone	154	98,000
Collalo Stone	152	82,000

OF MORTARS AND CEMENTS.

54. In the construction of works in Masonry, we generally employ some kind of cementitious matter for connecting the stones together, and rendering them firm and compact. When the works are to be exposed to the action of water immediately after being built, this cementitious matter must be of such a nature, that it will harden under water. Hence it is, that we have occasion for two kinds of mortar, one that will set and harden under water, called by Smeaton a *water-mortar*, or cement; and *common mortar* for ordinary buildings.

55. *Common Mortar*, it is almost superfluous to say, is a preparation of lime and sand, mixed with water, which serves to unite the stones, in the building of walls, &c., and on the proper or improper manner in which such mortar is prepared and used, depends the durability and security of buildings; we shall, therefore, here introduce many particulars on this head, discovered by Smeaton, Dr. Higgins, &c., but which, not being generally known, have never been introduced into general practice.

56. Limestone, marble, chalk, or shells, may be used to burn for lime for common mortar, all these substances being composed chiefly of lime and carbonic acid; and if a piece of one of them be slowly burnt or calcined, so as to expel the whole, or nearly the whole, of its carbonic acid, it loses about 44 per cent. of its weight; and when a small quantity of water is added to the calcined matter, it swells, gives out heat, and falls into a finely-divided powder, called *slacked lime*. The bulk of the powder is about double that of the limestone. If this powder be rapidly formed into a stiff paste with water, it sets or solidifies as a hydrate of lime, and ultimately hardens by the absorption of carbonic acid from the air. This constitutes common building-mortar. Hydrate of lime consists of 100 parts of lime, and 31 parts of water. Common limestone consists of carbonate of lime, with very little of any other substance; it produces a white lime, which slacks freely when well burnt; it dissolves in diluted muriatic acid, with only a small portion of residue, and never contains more than a trace of iron. It differs much in external characters, as chalk, marble, common compact limestone, &c.

These limestones do not form cements to set in water, without the addition of other kinds of cementing matter; hence they are usually employed only for common mortar. The hardest marble and the softest chalk make equally good lime when well burnt; but chalk-lime will slack when not perfectly burnt, and, therefore, seldom has a sufficient quantity of fire; whereas stone-lime must have sufficient to make it slack. It was also observed by Dr. Higgins, that stone-lime does not re-absorb carbonic acid so rapidly as chalk-lime

Lime, made from common limestones, sustains very little injury from being kept after it has been formed into mortar, provided the air be effectually excluded; indeed, Alberti mentions

an instance of some which had been covered up in a ditch for a very long time, and yet was found to be of an excellent quality.

57. Sand.—To employ lime alone in the composition of mortar would render it expensive, besides, it would be of inferior quality. The material commonly used to mix with lime is sand, and this sand should be of a hard nature, not very fine, but angular, and having a considerable degree of affinity for lime, also the more irregular it is in size the better. It should be free from any mixture of soft or earthy matter, if it can be procured without. The reason is obvious; for mortar, composed of soft sand, cannot be harder than that sand. Sea-sand makes good mortar, particularly water-mortar. Very hard-burnt brick, or tile, reduced to a coarse powder, also makes an excellent substance to mix with lime, for many purposes.

The best proportion of sand, for common mortar, is easily ascertained by trial; enough should be added to render the mortar rather short than tough under the trowel. The proportion varies from 4 parts of sand to 1 of lime, to 1¼ parts of sand to 1 of lime, by measure, the proportion differing according to the coarseness of the sand, the nature of the limestone, and the precautions used in burning it; all set proportions being universally adhered to only by those who are utterly ignorant of the subject. In many situations, it is impossible to procure good sand, except at an enormous expense.

58. Making Mortar.—The instructions given by Dr. Higgins for making stucco-mortar, apply only when a very superior kind is wanted; but the same general principles ought to be followed even with the commonest kinds of mortar. We will, therefore, insert them in this place.

Of *Sand*, the following kinds are to be preferred; first, *drift-sand*, or *pit-sand*, which consists chiefly of hard quartose flat-faced grains, with sharp angles; secondly, that which is the freest, or may be most easily freed by washing, from clay, salts, and calcareous, gypseous, or other grains less hard and durable than quartz; thirdly, that which contains the smallest quantity of pyrites, or heavy metallic-matter, inseparable by washing; and fourthly, that which suffers the smallest diminution of its bulk in washing. Where a coarse and fine sand of this kind, and corresponding in the size of their grains with the coarse and fine sands hereafter described, cannot be easily procured, let such sand of the foregoing quality be chosen as may be sorted and cleansed in the following manner:—

Let the sand be sifted in streaming clear water, through a sieve which shall give passage to all such grains as do not exceed one-sixteenth of an inch in diameter; and let the stream of water, and the sifting, be regulated so that all the sand which is much finer than the Lynn-sand, commonly used in the London glass-houses, together with clay, and every other matter specifically lighter than sand, may be washed away with the stream; whilst the purer and coarser sand, which passes through the sieve, subsides in a convenient receptacle, and the coarse rubbish and rubble remain on the sieve to be rejected.

Let the sand, which thus subsides in the receptacle, be washed in clean streaming water through a finer sieve, so as to be further cleansed, and sorted into two parcels; a coarser, which will remain in the sieve, which is to give passage to such grains of sand only as are less than one-thirtieth of an inch in diameter, and which is to be saved apart under the name of *coarse sand;* and a finer, which will pass through the sieve and subside in the water, and which is to be saved apart under the name of *fine sand.* Let the coarse and the fine sand be dried separately, either in the sun, or on a clean iron plate, set on a convenient surface, in the manner of a sand-heat.

Let *stone-lime* be chosen, which heats the most in slaking, and slakes the quickest when duly watered; that which is the freshest made and closest kept; that which dissolves in distilled vinegar with the least effervescence, and leaves the smallest residue insoluble, and in the residue the smallest quantity of clay, gypsum, or martial matter. Let the lime, chosen according to these rules, be put in a brass-wired sieve, to the quantity of fourteen pounds. Let the sieve be finer than either of the foregoing; the finer the better it will be: let the lime be slaked, by plunging it into a butt filled with soft-water, and raising it out quickly, and suffering it to heat and fume; and, by repeating this plunging and raising alternately, and agitating the lime until it be made to pass through the sieve into the water; and let the part of the lime which does not easily pass through the sieve be rejected: and let fresh portions of the lime be thus used, until as many ounces of lime have passed through the sieve as there are quarts of water in the butt.

Let the water, thus impregnated, stand in the butt closely covered until it becomes clear, and through wooden cocks, placed at different heights in the butt, let the clear liquor be drawn off, as fast and as low as the lime subsides, for use. This clear liquor is called *lime-water.* The freer the water is from saline matter, the better will be the cementing liquor made with it.

Let fifty-six pounds of the aforesaid chosen lime be slaked, by gradually sprinkling the lime-water on it, and especially on the unslaked pieces, in a close clean place. Let the slaked part be immediately sifted through the last mentioned fine brass-wired sieve: let the lime which passes be used instantly, or kept in air-tight vessels; and let the part of the lime which does not pass through the seive be rejected. This finer and richer part of the lime, which passes through the sieve, may be called *purified lime.*

Let bone-ash be prepared in the usual manner, by grinding the whitest burnt bones; but let it be sifted, so as to be much finer than the bone-ash commonly sold for making cupels.

The best materials for making the cement being thus prepared, take fifty-six pounds of the coarse sand, and forty-two pounds of the fine sand; mix them on a large plank of hard wood placed horizontally; then spread the sand so that it may stand to the height of six inches, with a flat surface on the plank, wet it with the lime-water, and let any superfluous quantity of the liquor, which the sand in the condition described cannot retain, flow away off the plank. To

the wetted sand add fourteen pounds of the purified lime, in several successive portions; mixing and beating them up together, in the mean time, with the instruments generally used in making fine mortar: then add fourteen pounds of the bone-ash, in successive portions, mixing and beating all together.

The quicker and the more perfectly these materials are mixed and beaten together, and the sooner the cement thus formed is used, the better it will be. This may be called *coarse-grained cement*, which is to be applied in building, pointing, plastering, stuccoing, or other work, as mortar and stucco generally are; with this difference chiefly, that, as this cement is shorter than mortar, or common stucco, and dries sooner, it ought to be worked expeditiously in all cases; and, in stuccoing, it ought to be laid on by sliding the trowel upwards on it. The materials used along with this cement in building, or the ground on which it is to be laid in stuccoing, ought to be well wetted with the lime-water in the instant of laying on the cement. The lime-water is also to be used when it is necessary to moisten the cement, or when a liquid is required to facilitate the floating of the cement.

When such cement is required to be of a still finer texture, take ninety-eight pounds of the fine sand, wet it with the lime-water, and mix it with the purified lime and the bone-ash, in the quantities and in the manner above described; with this difference only, that fifteen pounds of lime, or thereabouts, are to be used instead of fourteen pounds, if the greater part of the sand be as fine as Lynn sand. This may be called *fine-grained cement*. It is used in giving the last coating, or the finish, to any work intended to imitate the finer-grained stones or stucco. But it may be applied to all the uses of the *coarse-grained cement*, and in the same manner.

When, for any of the foregoing purposes of pointing, building, &c., a cement is required much cheaper and coarse-grained than either of the foregoing, then much coarser clean sand than the foregoing coarse sand, or well-washed fine rubble, is to be provided. Of this coarse sand, or rubble, take fifty-six pounds, of the foregoing coarse sand twenty-eight pounds, and of the fine sand fourteen pounds; and, after mixing these, and wetting them with the cementing-liquor, in the foregoing manner, add fourteen pounds, or somewhat less, of the purified lime, and then fourteen pounds, or somewhat less, of the bone-ash, mixing them together in the manner already described. When the cement is required to be white, white sand, white lime, and the whitest bone-ash, are to be chosen. Gray sand, and gray bone-ash formed of half-burnt bones, are to be chosen to make cement gray; and any other colour of the cement is obtained, either by choosing coloured sand, or by the admixture of the necessary quantity of coloured talc in powder, or of coloured, vitreous, or metallic, powders or other durable colouring ingredients, commonly used in paint.

This cement, whether the coarse or fine-grained, is applicable in forming artificial stone, by making alternate layers of the cement and of flint, hard stone, or bricks, in moulds of the figure of the intended stone, and by exposing the masses so formed to the open air, to harden.

When such cement is required for water-fences, two-thirds of the prescribed quantity of bone-ashes are to be omitted; and, in the place thereof, an equal measure of powdered terras is to be used; and, if the sand employed be not of the coarsest sort, more terras must be added, so that the terras shall be one-sixth part of the weight of the sand.

When such a cement is required of the finest grain, or in a fluid form, so that it may be applied with a brush, flint-powder, or the powder of any quartzose or hard earthy substance, may be used in the place of sand; but in a quantity smaller, in proportion as the flint or other powder is finer; so that the flint-powder, or other such powder, shall not be more than six times the weight of the lime, nor less than four times its weight. The greater the quantity of lime within these limits, the more will the cement be liable to crack by quick drying, and, *vice versâ*.

Where the above described sand cannot be conveniently procured, or where the sand cannot be conveniently washed and sorted, that sand which most resembles the mixture of coarse and fine sand above prescribed, may be used as directed, provided due attention be paid to the quantity of the lime, which is to be greater as the quality is finer, and, *vice versâ*.

Where sand cannot be easily procured, any durable stony body, or baked earth, grossly powdered, and sorted nearly to the sizes above prescribed for sand, may be used in the place of sand, measure for measure, but not weight for weight, unless such gross powder be specifically as heavy as sand.

Sand may be cleansed from every softer, lighter, and less durable, matter, and from that part of the sand which is too fine, by various methods preferable in certain circumstances, to that which has been already described.

Water may be found naturally free from fixable gas, selenite, or clay; such water may, without any great inconvenience, be used in the place of the lime-water; and water approaching this state will not require so much lime as above prescribed to make the lime-water; and a lime-water sufficiently useful may be made by various methods of mixing lime and water in the described proportions, or nearly so.

When stone-lime cannot be procured, chalk-lime, or shell-lime, which best resembles stone-lime, in the foregoing characters of lime, may be used in the manner described, excepting that fourteen pounds and a half of chalk-lime will be required in the place of fourteen pounds of stone-lime. The proportion of lime, as prescribed above, may be increased without inconvenience, when the cement or stucco is to be applied where it is not liable to dry quickly; and, in the contrary case, this proportion may be diminished. The defect of lime, in quantity or quality, may be very advantageously supplied, by causing a considerable quantity of lime-water to soak into the work, in successive portions, and at distant intervals of time; so that the calcareous matter of the lime-water, and the matter attracted from the open air, may fill and strengthen the work.

The powder of almost every well-dried or burnt animal substance may be used instead of bone-ash; and several earthy powders, especially the micaceous and the metallic; and the elixated ashes of divers vegetables, whose earth will not burn to lime, as well as the ashes of mineral fuel, which are of the calcareous kind, but will not burn to lime, will answer the ends of bone-ash in some degree.

The quantity of bone-ash described may be lessened without injuring the cement; in those circumstances especially which admit the quantity of lime to be lessened, and in those wherein the cement is not liable to dry quickly. The art of remedying the defects of lime may be advantageously practised to supply the deficiency of bone-ash, especially in building, and in making artificial stone with this cement.

As the preceding method of making mortar differs, in many particulars, from the common process, it may be useful to inquire into the causes on which this difference is founded.

When the sand contains much clay, the workmen find that the best mortar they can make must contain about one-half lime; and hence they lay it down as certain, that the best mortar is made by the composition of half sand and half lime.

But with sand requiring so great a proportion of lime as this, it will be impossible to make good cement; for it is universally allowed that the hardness of mortar depends on the crystallization of the lime round the other materials which are mixed with it; and thus uniting the whole mass into one solid substance. But, if a portion of the materials used be clay, or any other friable substance, it must be evident that, as these friable substances are not changed in one single particular, by the process of being mixed up with lime and water, the mortar, of which they form a proportion, will consequently be, more or less, of a friable nature, in proportion to the quantity of friable substances used in the composition of the mortar. On the other hand, if mortar be composed of lime and good sand only, as the sand is a stony substance, and not in the least friable, and as the lime, by perfect crystallization, becomes likewise of a stony nature, it must follow, that a mass of mortar, composed of these two stony substances, will itself be a hard, solid, unfriable, substance. This may account for one of the essential variations in the preceding method from that in common use, and point out the necessity of never using, in the place of sand, which is a durable stony body, the scrapings of roads, old mortar, and other rubbish, from antient buildings, which are frequently made use of, as all of them consist, more or less, of muddy, soft, and minutely divided particles.

Another essential point is the nature and quality of the lime. Now, experience proves that, when lime has been long kept in heaps, or untight casks, it is reduced to the state of chalk, and becomes every day less capable of being made into good mortar; because, as the goodness or durability of the mortar depends on the crystallization of the lime, and, as experiments have proved, that lime, when reduced to this chalk-like state, is always incapable of perfect crystallization, it must follow that, as lime in this state never becomes crystallized, the mortar of

which it forms the most indispensable part, will necessarily be very imperfect; that is to say, it will never become a solid stony substance; a circumstance absolutely required in the formation of good durable mortar. These are the two principal ingredients in the formation of mortar; but, as water is also necessary, it may be useful to point out that which is the fittest for this purpose; the best is rain-water, river-water the second, land-water next, and spring-water last.

The ruins of the antient Roman buildings are found to cohere so strongly, as to have caused an opinion that their constructors were acquainted with some kind of mortar, which, in comparison with ours, might justly be called *cement:* and that, to our want of knowledge of the materials they used, is owing the great inferiority of modern buildings in their durability. But a proper attention to the above particulars would soon show that the durability of the antient edifices depended on the manner of preparing their mortar more than on the nature of the materials used. The following observations will, we think, prove this beyond a possibility of doubt:

Lime, which has been slaked and mixed with sand, becomes hard and consistent when dry, by a process similar to that which produces natural *stalactites* in caverns. These are always formed by water dropping from the roof. But, when the small drop of water comes to be exposed to the air, the calcareous matter contained in it begins to attract carbonic acid from the atmosphere. In proportion as it does so, it also begins to separate from the water, and to re-assume its native form of lime-stone or marble. When the calcareous matter is perfectly crystallized in this manner, it is to all intents and purposes lime-stone or marble of the same consistence as before. If lime, in a caustic state, be mixed with water, part of the lime will be dissolved, and will also begin to crystallize. The water which parted with the crystallized lime will then begin to act upon the remainder, which it could not dissolve before; and thus the process will continue, either till the lime be all reduced to an *effete*, or crystalline state, or something hinders the action of the water upon it. It is this crystallization which is observed by the workmen when a heap of lime is mixed with water, and left for some time to macerate. A hard crust is formed upon the surface, which is ignorantly called *frostling*, though it takes place in summer as well as in winter. If, therefore, the hardness of the lime, or its becoming a cement, depends entirely on the formation of its crystals, it is evident that the perfection of the cement must depend on the perfection of the crystals, and the hardness of the matters which are entangled among them. The additional substances used in making of mortar, such as sand, brick-dust, or the like, serve only for a purpose similar to what is answered by sticks put into a vessel full of any saline solution; namely, to afford the crystals an opportunity of fastening themselves upon it. If, therefore, the matter interposed between the crystals of the lime is of a friable brittle nature, such as brick-dust or chalk, the mortar will be of a weak and imperfect kind; but, when the particles are hard, angular, and very difficult to be broken, such as those of river or pit-sand, the mortar turns out exceedingly good and strong. That the crystallization may be the more perfect, a large quantity of water should

be used, the ingredients be perfectly mixed together, and the drying be as slow as possible. An attention to these particulars, and to the quality of bricks and stones, would make the buildings of the moderns equally durable with those of the antients. In the old Roman works, the great thickness of the walls necessarily required a vast length of time to dry. The middle of them was composed of pebbles thrown in at random, and which, evidently, had thin mortar poured in among them. Thus a great quantity of the lime would be dissolved, and the crystallization performed in the most perfect manner. The indefatigable pains and perseverance, for which the Romans were so remarkable in all their undertakings, leave no room to doubt that they would take care to have the ingredients mixed together as well as possible. The consequence of all this is, that the buildings formed in this manner are all as firm as if cut out of a solid rock; the mortar being equally hard, if not more so, than the stones themselves.

59. Water-Mortars or Cements.—The cementing materials are either found ready combined in certain kinds of stone, as in the case of Roman cement; or the effect is produced by mixture, as when we mix the lime of poor lime-stones with Dutch terras. The natural combination is, however, by far the best; and it is only in cases where the other can be obtained at a much less expense, that we advise it to be resorted to; but, for such cases, we propose to describe the best compositions now known.

60. *Roman Cement* is made from the kind of stones called clay-balls.* The best stone contains about 60 per cent. of carbonate of lime, and 8 or 10 per cent. of protoxide of iron, the rest being silex and alumine nearly in equal parts. The inferior stones contain peroxide of iron, and often soluble earthy and alkaline salts. Stone of the best kind is procured on the coast of the Isle of Sheppy, and from the alum-shale on the coast of Yorkshire, near Whitby. Stone of an inferior quality is procured near Harwich, and other places on the coast of England, and at Boulogne, in France. The stone is, after being broken to a proper size, slowly calcined in kilns or ovens, and then it is ground to a fine powder, of a light snuff-colour, when the stone is good; and of a deeper, approaching to a burnt-umber brown, when the quality is inferior. The powder should be kept perfectly dry till it is to be used; and, in order to use it, mix it with not less than an equal portion, by measure, of dry, clean, and sharp, river-sand; then add as much clear water as will form it into a stiff paste, but not more; and the whole that is so mixed must be used before it begins to set, which, with good cement, happens in about fifteen minutes from the time of adding the water; but, in cements very fit for building, the setting may not be commenced in less than half or three-quarters of an hour. When the setting begins, all the moisture on the surface disappears, and the cement feels dry and warm to the touch, and hardens; the hardening continues for some months, and is increased by frequent wetting the work, in cases where it has not to be exposed to water immediately on its being set. A coat of this cement is impervious to water, and it is therefore most extensively used for lining cisterns, tanks, reservoirs, &c.

* They are by some called *septaria*, from being generally divided by thin septa of carbonate of lime; and by other, *ludus helmontii*

61. Roman Cement may be used alone, but it does not become so hard and durable, as when it has a proper quantity of good sand mixed with it. A mixture of Roman cement and common mortar should never be made, for their setting properties depend on different combinations, and which interfere with each other when acting in the same mass; and the best mortar and best cement may be both rendered worthless by mixture. In using cement, the more expeditious the workman is in his operations the better; and when once setting has commenced, the work should be no further disturbed. If the setting take place too rapidly for the nature of the work, let the cement, in powder, be spread out so as to expose a large surface to the air in a dry place; in this manner the time of setting may be extended according to the time the powder is exposed, and though the quality of the cement is injured by the process, it is not so much destroyed as by working the cement after its being partially set.

62. *Puzzolana Mortar.*—An excellent mortar for water-works is formed by combining the lime of poor lime-stones with the earth, called puzzolana, which is procured in Italy. The lime-stones adapted for this purpose are the blue lias of Somersetshire, the clunch of Sussex, and the hard gray chalk of Surrey. Smeaton used the lime of the lias procured at Aberthaw, in Wales, for the Eddystone light-house; the proportions as under—

Kind of Mortar.	Lime in Powder.	Puzzolana.	Clean Sand.
No. 1. Eddystone Mortar	2 bushels.	2 bushels.	——
2. Stone Do.....	2 ——	1 ——	1 bushel.
3. Do. 2d sort	2 ——	1 ——	2 ——
4. Face Mortar.....	2 ——	1 ——	3 ——
5. Do. 2d sort	2 ——	½ ——	3 ——
6. Backing Mortar	2 ——	¼ ——	3 ——

Smeaton remarks, that mortar, of the proportions of No. 1, will, in twelve months, acquire the hardness of Portland stone, when under water; and the others will, in time, acquire a stony hardness, if the materials have been thoroughly mixed and well beaten together. An article, called British puzzolana, has lately been manufactured, but it does not possess the same properties as the foreign kind; and, indeed is rather a substitute for sand than for the true puzzolana.

63. *Terras Mortar,* is also very good for water-works; it is composed of an earthy material called terras, found near Andernach, in the department of the Rhine and Moselle, which is mixed with any lime of a nature similar to the blue lias. Terras is much used by the Dutch for their sea and canal works, and it has the singular property of forming stalactitical excrescences at the joints of the work. Smeaton employed it in the following proportions, according to the nature of the work, No. 1. being the best quality:—

Kind of Mortar.	Lime in Powder.	Terras.	Clean Sand.
No. 1. Terras Mortar	2 bushels.	1 bushel.	——
2. Do. 2d kind	2 ——	1 ——	1 bushel.
3. Do. 3d kind	2 ——	1 ——	2 ——
4. Do. 4th kind	2 ——	1 ——	3 ——
5. Backing Mortar	2 ——	½ ——	3 ——

The customary allowance of beating for terras-mortar is a day's work of a man for every bushel of terras.

64. When neither Roman cement, puzzolana, nor terras, can be procured, except at great expense, then we may have recourse to calcined iron-ore, scales from smith's forges, calcined basalt, clay, and other substances, containing a considerable proportion of protoxide of iron. Lime may also be improved by peculiar treatment in burning, for it appears that even common chalk-lime acquires a setting property resembling that of the lias-lime, by being long exposed to a certain degree of heat.

65. All limes fit for water-cements require to be ground to powder, and the finer the better. If these limes be slacked, the setting property is partially destroyed; and it is important that no more mortar should be made up at once than can be used within a few hours.

CHAPTER III.

OF THE CONSTRUCTION OF FOUNDATIONS.

66. A SUBSTANTIAL foundation is of the first importance in masonry, as without it no work can be durable; and yet its construction is usually intrusted to the carpenter and bricklayer: the former for piling the inferior, soft, or marshy grounds; and the latter for raising the wall with little or no masonry to the level of the ground.

PLANKING consists in bedding strong boards of oak or fir, of the whole length and breadth of the foundation: those of oak not less than three inches, and of fir five, in thickness; and they are sometimes scorched all over, previously to being laid down; but many dilapidations having been occasioned by the decay of planks, the use of them has, by judicious architects, been lately abandoned; and large stones, set in cement, used instead.

67. PILING is had recourse to, where the magnitude of the superstructure requires that a more solid stratum of earth should be pierced for its support. The piles, which are forced into the

earth, are made of fir, oak, &c., usually about nine or ten inches square. Their length is ascertained by boring the ground; the ends of the piles are cased or shoed with pointed iron, and the tops surrounded with a hoop of the same metal. The machine for driving these piles consists of a frame of wood, braced by strong pieces of timber, and secured by ledgers and feet; with a cast-iron wheel at the top, about eighteen inches in diameter, and fluted on the outside for a rope, or chain, to move in. This rope, or chain, is attached to the axis of a heavy iron beater, called the ram, which, for general use, weighs about five or seven hundred weight. This ram slides sometimes in grooves, in the upright frame, and often on the frame of the upright. A ladder is attached for adjusting the chain, and oiling the machine. It is worked by twenty or more men, each taking hold of a rope for that purpose, and thus raising the beater up and down in the frame. When many piles are to be driven, double sets of men to work the beater alternately will be necessary. The piles are driven as near together as may be considered proper to support the building, and the tops sawn off level, and the intervals filled up, by the Romans with charred substances, and by us with chalk, stone, and rubble; and the tops *planked* over to receive the stone-work.

In works exposed to water, the base is encircled by plank-piling; these piles are all grooved on their opposite sides; and, when driven close to each other, a tongue is forced between to bind the whole together, so as to produce a close chain of wooden piling, from one end of the foundation to the other.

68. Some architects have not deemed either planking or piling eligible for foundations, within infirm or swampy grounds; and have, therefore, had recourse to a cradle of oak, or fir, in quartering, strongly framed and braced together in bays, and in lengths of from five to ten feet, and of widths proportionate to the weight of the superstructure: these frames are again covered over by cross-pieces, or joists, and the whole bedded firmly on the ground, and filled up flush with brick or stone, bedded in water-cement. (See *art.* 59, &c.) The foundation of brick or stone walls, laid on this, has been found safer than planking; because, if the quarters of the cradle should decay, the connected work between would still remain united, and consequently the sinking of the building would be regular, though not altogether prevented.

69. The FOUNDATIONS of BRIDGES are generally laid dry at the piers, by the water's being, for a time, turned into a new course, or by erecting a coffer-dam. A *coffer-dam* consists of a double chain of piles, driven into the ground, at a sufficient distance from the intended pier, to admit the work's being conveniently proceeded in; when the piles are all firmly fixed in the earth, strong horizontal beams are framed and bolted to them with braces to stiffen the intermediate parts; they are then finally planked inside and out, so as to form a complete case. The void between each casing is then filled with loam or clay, so that very little water can percolate, and what does get in is removed by pumping. A more ingenious method has, however been practised. It consists of forming a strong grating of timber, covered with planks,

which at once forms a floating-raft, and the floor upon which the stone pier is to be erected the pier built on the raft is composed of stones, amply secured, and rendered, by cement, water-tight; and the whole is so arranged as to float upon the water till it has advanced in height; so that, if sunk, it should be above low-water mark, or higher, as found expedient. This levity is obtained either by attaching the raft by ropes to vessels, or by the pier's being worked with vacuities sufficient to render it specifically lighter than an equal bulk of water. The pier is sunk either by letting the water into the vacuities, or by loosening the ropes; but the bed of the river should be previously prepared for its reception, by dredging-machines. Should the bottom of the ground prove not to be level, the pier must be raised by pumping the water out, or by means of the machines in the vessels, and the ground then satisfactorily levelled.

In the erection of Westminster Bridge, M. Labelye erected the piers in caissons, or water-tight boxes; the bulk of the box, though loaded with the pier, producing a mass specifically lighter than an equal bulk of water: after each pier had been erected, the sides of the box served again for boxes of other piers; the pier was sunk, and raised as above. Similar caissons were likewise used in erecting Blackfriars' Bridge.

Till of late years the foundation of bridges was erected in the following manner: The piles were driven into the bottom of the river, in the site of the intended pier, and then cut off a little below low-water mark; the interstices being filled with stone and strong cement; on these piles a grating of timber was laid, boarded with thick boarding, and thus was formed the floor for the intended pier. The work was then continued, at low-water This is a very simple method, requiring no machine beyond a pile-driving engine.

The foundations of the piers of London Bridge, as appeared from that which was removed, when the two small arches were converted into one, was composed of a quadruple row of piles, driven in close together on the exterior site of the pier, and forming a case to receive the stone and cement. So soon as the exterior piles were taken away, the force of the water cleared away the remainder, so that it could not be ascertained whether there were piles in the heart of the pier. To protect the piers of this bridge, sterlings were constructed round them. A *sterling* consists of an enclosure of piles driven close together into the bed of the river, and secured by horizontal pieces of timber, bolted by iron to the tops of the piles; and the void within, to the piling of the pier, filled with chalk, gravel, stone, &c., so as to form a complete defence to the internal piling, upon which the stone piers are erected.

CHAPTER IV

OF THE CONSTRUCTION OF WALLS.

70. The antients used several modes of constructing Walls, in which more or less masonry was always introduced. They had their *reticular* or reticulated *walls*, and also the *incertain*: of these, the *reticulative* kind (*plate* XIV, *fig.* 2,) was esteemed the most handsome; but the joints are so ordered, that, in all parts, the courses have a regular position; whereas, in the *incertain*, (*fig.* 1,) the materials rest irregularly one upon another; and are interwoven together, so that they are much stronger than the reticulated, though not so handsome. In the kind of wall represented in *fig.* 1, the courses are neither level, nor the upright joints ranged regularly or perpendicularly to each other in the alternate courses, nor in any other respect correspondently, but uncertainly, according to the size of the stone employed. Stones are so arranged in ordinary rubble walls, in which all that is regarded is, that the upright joints, in two adjoining courses, do not coincide. Walls, of both sorts, were formed of very small pieces, with a sufficient quantity of good mortar, which added greatly to their solidity.

To saturate, or fill up, a wall with mortar, is a practice which ought to be had recourse to in most cases, where small stones, or bricks, admit of it. It consists in mixing fresh lime with water, and pouring it, while hot, among the masonry in the body of the wall.

The walls called by the Greeks *Isodomum*, (*fig.* 4,) are those in which all the courses are of an equal thickness; and *Pseudo-isodomum*, (*fig.* 3,) those when they are unequal. Both these walls are firm, in proportion to the compactness of the mass, and the solid nature of the stones, so that they do not absorb the moistness of the mortar too rapidly; and, being situated in regular and level courses, the mortar is prevented from falling, and thus the whole thickness of the wall is united.

71. In the kind of wall called *emplection* by the Greeks, (*fig.* 6,) the faces were built with dressed stones, with the other sides left as they came from the quarry; and the two faces were secured by occasional bond-stones. This kind of building admits of great expedition, as the artificer can easily raise a case, or shell, for the two faces of the work, and fill the intermediate space with rubble-work and mortar. Walls of this kind, consequently, consist of three parts, with very imperfect connection; two being the faces, and the other a rubble core in the middle: but the great works of the Greeks were not thus built, for, in them, the whole intermediate space between the two faces was constructed in the same manner as the faces themselves (*fig.* 5); and they, besides, occasionally introduced *diatonos*, or single pieces, A, A, extending

from one face to the other, to strengthen and bind the wall. These different methods of uniting the several parts of the masonry of a wall, should be well considered by all persons who are intrusted with works requiring great strength and durability.

The existing examples of *Roman emplection*, with partial cores of rubble-work, or brick, sufficiently prove its durability when united by excellent mortar; of the Greek method, which was worked throughout the whole thickness of the wall, in the same manner as the facings or fronts, their temples, now existing, testify the solidity.

72. The stone in the walls of modern buildings is sometimes used for ornament, or covering of the brick-work, but is generally combined with solidity. In London, the thickness of walls is regulated by a specific Act of Parliament; but, to prevent dilapidation, it is often necessary to strengthen the walls beyond what the law requires, as this law was framed only as a protection from fire, and was only for brick-walls. The thicknesses of walls should be regulated according to the nature of the materials, and the magnitude of the edifice. Walls entirely of hewn stone may be made one-fifth thinner than those of brick; and brick-walls, in the basement and ground-stories of buildings of the first-rate, should have the facing-stones rusticated, to prevent their splitting; a circumstance which has been too much disregarded by our present builders.

73. A wall should be reduced in thickness as it rises, for the same reason that a column is diminished; and if the wall be a part of a house, it should be reduced in a still greater degree, since the load, which is to be supported by it at different parts of its height, is usually much varied, by the weight of the floors, and of the contents of the apartments; such walls are reduced by internal offsets, the external face of the wall having only a slight inclination, called battering, of about an inch in a height of 10 feet. The obliquity of the external surface of a wall may, however, become objectionable, by promoting the growth of moss and weeds. In building a wall, the first precaution that is required, is to dig deep enough to ascertain the nature of the ground; the next, to lay a sufficiently extensive and firm foundation; and it has been very properly recommended that where walls are wanted, the ground should be well examined before the foundations of a house be laid, in order to ascertain the qualities of the different strata which are to support them.

74. The disposition of the stones, or bricks, is of much importance; the strength of a wall or tower is obviously greatest when all the surfaces are either horizontal or vertical; for if they be oblique, they must have a tendency to slide away laterally, and the wall must be very liable to crack: hence the reticulated walls, sometimes employed by the antients, of which all the joints were oblique, possessed but little durability (*art.* 70). If the materials be put together without regular joints, the parts in contact tend to separate the walls by their action on each other; occasionally, as in the case of piers, or quays, this circumstance may be of some advantage in opposing external pressure, and uncoursed or rubble-work may be used; but no wall, composed of different kinds of masonry, is so strong as when wholly of one kind.

It is not unusual to make the external face of an inclosing wall of hewn stone, and the internal part of the wall of rubble-work; but these settle unequally, and where the walls support much weight dangerous cracks and bulges take place. The walls of St. Peter's Church at Rome show some serious defects arising from this cause.

75. It is not of much advantage in walls to use stones which have a greater length than three times their thickness; otherwise, from the difficulty of bedding them equally, they are liable to break in the wall; hence proper crossing of the joints with stones that are not so long as to have the risk of breaking, is a better method. In the angles and piers of a building, it is most necessary to attend to strength, both by bond and good-sized stones.

76. We have given the pressure which stones will bear with safety, and it will be useful to add the pressure actually borne by the principal supports of some of the most celebrated buildings in Europe.

NAMES OF THE BUILDINGS.	Pressure on each superficial foot.
The pillars of the Gothic church of All Saints at Angers	86,000 lbs.
The pillars of the dome of the Pantheon at Paris, the lower part of which are of Bagneux stone	60,000 —
The pillars which support the tower of the Church of St. Mary at Rome	60,000 —
The columns supporting the roof of the Basilica of St. Paul at Rome	41,000 —
The pillar in the centre of the Chapel-house at Elgin, which is of red-sandstone	40,000 —
The piers which support the dome of St. Paul's in London	39,000 —
The piers which support the dome of St. Peter's at Rome	33,000 —
The pillars supporting the dome of the Invalids at Paris	30,500 —
The pressure on the key-stone of the Bridge of Neuilly (see *plate* XIX, *fig.* 1) has been estimated at	18,000 —

The Bagneux stone should not, it appears from experiment, be loaded beyond the above, even on the supposition that the force is vertical, and in the axis of each pillar; hence, any irregularity in these respects renders the construction hazardous; and we are not surprised to find that the stones split, and exhibited manifest signs of being overloaded.

Of Wharf, Dock, and Revetment Walls, &c.

77. Walls have frequently to be built to resist the pressure of fluids, or of earth acting against their sides, and sometimes to resist the force of the waves of the sea; they require, therefore, to be most firmly built, and of a form and massiveness adapted to the object. In all these species of walls, it is the stress of earth against them that has chiefly to be considered, except in the case of sea-walls.

78. The most simple kind of wall is a rectangular one (*fig.* 1, *plate* XV.); but an equal degree of strength, with less material, is obtained by giving it an exterior slope, as *fig.* 2. For fortification, Vauban used to make this exterior slope $\frac{1}{5}$ of the height, but the joints perish, and mosses grow on and destroy walls having so much slope, hence later engineers make it less, $\frac{1}{6}$ of the height is commonly used, but $\frac{1}{8}$ or $\frac{1}{10}$ is, in our opinion, quite sufficient. To gain an equivalent in strength, we would adopt the countersloping form, *fig.* 3, or its equivalent, *fig.* 4. In some instances, the bulk of the wall has been increased, by leaving spaces in the work to be filled in with rubble, gravel, &c., as in *fig.* 5; and in others, sloping walls have been built as in *fig.* 6; and the latest change is to make the walls curved, as in *fig.* 7. The latter are very appropriate for docks and basins, but are not so fit for dry works.

79. The strength of any of these walls is materially increased by adding counterforts on the side next the earth, of a breadth about equal to the mean thickness of the wall, and about three times that thickness apart, (*fig.* 8,) and their thickness about three-quarters of their breadth. The strength of the wall should be such, that, were it deprived of counterforts, it would be sufficient to resist the pressure of the earth.

80. In order to consider the strength of walls to support earth, &c., it should be understood that the bank of earth itself may be sloped so that it will stand, and let this slope be ac (*fig.* 1, *plate* XV.); it is called the natural slope of the earth; and the angle it forms with the horizon is called the angle of repose. Now it is evident, that the triangular prism of earth sustained is abc; but, within that triangle, there will be found another, dab, which, though it be less in weight, has more force to overturn the wall, because it is a more acute wedge; the line da then is the line of fracture, and it has been shown by Mr. Tredgold, that, when the forces are found in a horizontal direction, the pressure on a foot in length, tending to overturn the wall, is—

$$\frac{h^2 s}{2} c^2; \text{ and, its effect, } \frac{h^3 s c^2}{6}.$$

Where h is the height of the wall in feet, s the weight of a cubic foot of the earth, and c^2 the square of the cotangent of half the angle of repose of the earth.

81. In treating of the resistance of walls, we shall omit the effect of the coherence of the mortar, and of the earth, because a wall generally has the whole stress upon it before the mortar be set, or the earth has become compact; and, also, when a wall oversets, it cannot be sustained by a mere arris, but the angle would crush and shorten the leverage the weight of the wall acts with, the amount of this shortening may be estimated at $\frac{1}{6}$ of the leverage of the wall at the base.

Now, in all walls, the height h in feet, multiplied by t, the mean thickness in feet, and by w, the weight of a cubic foot of the masonry, will give the weight of a foot in length; that is, htw = the weight; and the leverage is equal to the distance nt therefore, $\frac{5ht^2wn}{6}$ = the resistance of the wall, and making it equal to the pressure of the earth, or $\frac{5ht^2wn}{6} = \frac{h^2sc^2}{6}$; we have $t = hc\sqrt{\frac{s}{5wn}}$.

82. For rectangular stone walls, (*fig.* 1,) to support common earth, $n = \frac{1}{2}$; $w = 130$; $s = 96$ lbs., and $c = \cdot 56$; therefore, $t = \cdot 3\,h$, or the thickness of the wall in feet should be three-tenths of its height in feet.

83. For sloping walls, (*fig.* 2,) with a slope of $\frac{1}{6}$th, then $n = .6043$, and t being the mean thickness, the conditions being in other respects the same as the last, $t = \cdot 27\,h$.

84. If the wall have offsets at the back, (*fig.* 4,) it will be proper to make the weight of the mass, *a b e f*, of equal weight to a rectangular wall, found by *art.* 82; but a sloping back has much more stress upon it.

85. In a sloping wall, (*fig.* 6,) if the slope *g e* be m times the mean thickness of the wall, then $n = \frac{m+1}{2}$ and $t = hc\sqrt{\frac{2s}{5w(m+1)}}$; and, when the slope is equal to the mean thickness, for common earth and stone walls, we have $t = \cdot 215\,h$, or the thickness of the wall, measured horizontally, should be ·215 times its height.

86. A wall ought to be so constructed that the resultant of the pressures should every where fall within the thickness of the wall; and a careful investigation of this problem will show that a curved wall of a particular form is the best possible. If a plain wall be not of sufficient thickness to admit the curve to be drawn within it, there will be a tendency to bulge at one-third of the height from the base; hence, for all sloping walls, we should give the preference to the curved forms. (See *fig.* 7, 9, and 10.)

87. Where walls have to resist the pressure of water, or other fluid matter not materially heavier, the general rule becomes $t = h\sqrt{\frac{62{\cdot}5}{5wn}} = h\sqrt{\frac{12{\cdot}5}{wn}}$.

For a common stone rectangular wall, (*fig.* 1,) $w = 130$ lbs., and $n = \frac{1}{2}$, therefore $t = \cdot 44\,h$; or the height of the wall multiplied by ·44, is equal to the proper thickness.

88. If the wall has a slope of one-sixth, (as *fig.* 2,) then the mean thickness should be four-tenths of the height.

89. The preceding rules are so easily applied, that we have not added tables; but, in preference, describe some of the most important works of this kind that have been executed. In revetment walls, for fortification, the celebrated Vauban always used an exterior slope of $\frac{1}{5}$, and made the wall $5\frac{1}{3}$ feet at the top, and the back vertical. He made diminished counterforts at from 15 to 18 feet apart; for a wall ten feet high the counterfort had a length of 4 feet, and a breadth of 3 feet at the root and 2 feet at the tail; and for every additional foot in height he added 3·6 inches to the length, and ·8 in. to the breadth of the counterforts. The exterior slope is less in later works.

90. Of Dock-walls, there are many examples, chiefly of the curved form, which was first used by Jessop, for the West-India Docks. The height of the walls of which are 29 feet; the face-curve is described by a radius of 72 feet, from a centre level with the top of the wall, (see *fig.* 9,) the thickness of the wall is 6 feet, and uniform, and the counterforts 3 ft. by 3 ft., and

18 feet apart. As the slope is, in this case, very nearly the same as the thickness of the wall, the rule (*art.* 85) ought to apply, which gives 6·2 feet for the mean thickness.

Where less than the mean thickness is sufficient for resisting the wear and tear at the top of the wall, there will be considerable advantage in increasing the thickness of the base, as has been done by Mr. Walker, at the entrance-basin of the East-India Docks (see *fig.* 10); the wall of which is 22 feet high, 7½ feet at the base, and 3½ feet at the top; the counterforts 2½ feet wide, 1½ feet at the top, and 7½ feet at the bottom, the backs of them being vertical.

91. As an example of a *sea-wall*, we have given the section of one built at Liverpool in 1806 (*fig.* 11); the height is 30 feet; the base 15 feet, and top 7½ feet, with a front slope of one in 12; the counterforts are 15 feet wide, and 36 feet from centre to centre. But, for a wall to defend any place from the force of the ocean, a long slope, in form resembling the sea-beach, only rising more rapidly, should be made. The section of the celebrated *Breakwater*, at Plymouth, is shown, (*fig.* 12, *plate* XV,) but it is a straight-lined figure, and wants a connected surface next the Channel, to render it an effective means of resisting the force of the waves. It is formed by dropping large masses of stone, 1½ to 2 tons in weight, in such a manner as to obtain the figure shown in the section. There was 4,233 feet in length finished in 1825.

92. In order to secure walls, by completely uniting the masses of stone together, dove-tailing, dowels of hard stone, or of cast-iron, cramps run in with lead, and various other methods are used; of these, the best is locking the stones by dovetail-joints, (*plate* XXIII, *fig.* 3,) and filling them with cement (see *art.* 60).

CHAPTER V.

OF THE CONSTRUCTION OF BRIDGES, &c.

93. The construction of Bridges is an art of immense importance; as it largely contributes towards the improvement of that system of internal communication which diffuses the benefits of industry and trade throughout the British Empire.

In the theory of the construction of bridges, mathematical science, in all its dignity, is exercised, and to the enlightened mechanical mind, it has, therefore, always been a favourite subject. To him especially who delights in ranging the delightful truths of geometry, and in employing the higher powers of analysis, and who feels, as he contemplates them, that enthusiastic emotion which poets and philosophers alone can know. There are few operations of art to which the man of science can apply his speculative principles more successfully than to the

building of bridges; theory, however, did not at one period keep pace with practice, but now, through recent improvements, science will have a potent influence in directing the operations of the mechanic, and the carpenter and builder will lean, with full confidence, on the deductions of the mathematician.

The construction of bridges is a subject in itself highly interesting; from the difficulty attending their erection, and the ingenuity displayed, both have much power over a contemplative mind, and in common ones excite astonishment. What, indeed, can be more striking than to see a huge mass of ponderous stones, suspended, by the mutual balance of its parts, over the mightiest river in the world? and, so far has the intrepidity of the engineer carried him, that bridges are thrown over arms of the sea; and here, also, has success been complete. The boldness of form and grandeur of effect is not a greater source of astonishment than the neatness and elegance of the structures. Holding at nought the danger attending their labour, the workmen must show their skill in preparing, placing, and embellishing, their materials, as if ornament, more than utility, were the object of their wishes: but, generally, it will be found that, while ornament is obtained, utility is the main object of the design, and that the stones are so artfully constructed and laid together, that, in combination, they may give mutual support, and the heaviest load may pass over in perfect safety.

The construction of a perfect bridge is, however, a very complex operation; it could not be accomplished by a rude and unintelligent people; and we find, in the history of bridges, that the erection of arches did not always correspond with the progress of other arts, even where an advantageous intercourse subsisted.

94. The SIMPLEST BRIDGE is obviously that which is composed of a single tree, thrown across a small stream, whose width is not too great for the length of the tree; but, when this is the case, a higher effort of inventive power is necessary, and this is also soon supplied by stretching another tree from the opposite side, and fastening them together in the middle, by some means or other, such as twisting the branches. This sort of bridge must frequently occur by chance. Mr. Park found such in the interior of Africa.

95. The next step is not much more complex; for the process of twining ropes of fibrous bark or leathern thongs is very simple; and we have only to connect together and stretch as many as may be necessary, from one tree to another, on the opposite banks of the stream, and cover them so as to answer the purpose required. Bridges of this kind have been constructed in South-America and in India, and the principle has been improved upon in Britain by using chains of iron instead of rope or leather; the first bridge of the kind was thrown across the Tees at Winston, and the most splendid is that which has been erected, by Telford, over the Straits of Menai for the mail-road to Holyhead, the span of the bridge being 560 feet; and the abutments and towers for fixing the chains are fine specimens of masonry. (See *plate* XX.)

A suspension bridge of this kind has just been completed over the Thames at Hammersmith. The suspension towers are 400 feet apart, built of hewn stone, and designed as archways

of the Tuscan order, the towers are 22 feet thick, and of the breadth of the bridge, and rise 48 feet above the roadway; they have the singular and evident defect of having no passage for foot passengers. The retaining piers on the shores are built of brick and stone firmly cemented together, with tunnels for the chains to pass through.

96. The next mode of forming bridges is to construct piers of stone, at such a distance from each other, as to admit a beam of timber, or a long single stone, to stretch over the width of the stream. This, if the water be shallow, is a very simple operation; for the piers may be built of rough stone without mortar, and such a process would soon present itself to a rude people.

But, if the stream be at all times rapid and deep, and the piers built of hewn stone laid with mortar, we may infer that the people who formed such a structure were well acquainted with the useful arts; for it is clear that the stones must previously have been quarried and hewn, and before a proper foundation for the pier could be had, the union and experience of various arts were required: hence, then, we conclude that the society in which a work of this sort, of any considerable magnitude, is accomplished, is far advanced in civilization, and has the command of much well-regulated labour.

97. With respect to the mode, now commonly adopted, of constructing arches between piers of stone, the Chinese pretend that they erected bridges in this manner many centuries before arches were known in Europe, or to the inhabitants of any part of the western world: but, when we consider the many specious claims that this empire has held forth for the high antiquity of its improvements and inventions, we may perhaps feel but little disposed to credit the assertion.

In Egypt and in India, countries of the highest antiquity, and which have produced many useful inventions, both in science and in art, the construction of the arch appears not to have been known; for the temples of the one, and the tombs of the other, were produced by cutting matter away in the manner of sculpture: and further, in the antient works of Persia and Phœnicia no trace of an arch can be found. The Greeks created a school of architecture and sculpture, and carried their knowledge very far in these departments, yet even they have but an obscure claim to the knowledge of the arch. It is, at least, certain that they never used it externally in their temples, much less in the construction of bridges.

It is to the Romans, then, that we are indebted for this useful application of a great principle in architecture; but there is no certainty as to the time when it was first practised. It is asserted, by some, that the Romans derived their knowledge of the arch from the Etruscans; but, if this were admitted, the first knowledge of the art is at least very intimately connected with Greece, for we believe it is not disputed that the Etruscans were a colony of Dorians.

But, however doubtful may be the claim to the invention of the arch, we know, from history, that the Romans were the first to apply it to useful purposes; the oldest known example being the Cloacæ Maxima of Rome, and it was soon afterwards used in forming aqueducts for convey-

ing water to cities, erecting bridges over rivers, vaulting temples, and the like, and in erecting monuments to record the exploits of their heroes.

98. Having thus described the rude bridges of uncivilized nations, and shown that the Romans were the first to perfect and bring the arch into common use, we shall pass over the description of most of the massy structures of this kind that have been reared in other countries, and confine ourselves chiefly to those which are conspicuous in our own kingdom, beginning with the old BRIDGE of LONDON.

This bridge was originally begun in the year 1176, by a priest, called Peter, curate of St. Mary Colechurch, a celebrated architect of those times, and occupied thirty-three years in building: but this period will not appear surprising, when it is considered that it was built over a river in which the tide rises, twice every day, from 13 to 18 feet. The bridge at first consisted of twenty arches, and houses were erected on each side of the roadway; but, in 1758, the middle pier was taken down, and the two adjacent arches were converted into one, the span of which was seventy-two feet; its breadth forty-five feet, and the houses along each side of it were removed. The remaining arches were very narrow, and the piers inconveniently large, being from fifteen to twenty-five feet in thickness. The passage over the bridge was very commodious, but in other respects there was nothing to recommend it, and the fall of water under it, from the obstruction of the piers and sterlings, with the difficulty of preserving the bases of the piers from failure, rendered it necessary to build a new bridge.

99. The foundation-stone of WESTMINSTER BRIDGE was laid on the 24th of January, 1739, by the Earl of Pembroke (a nobleman distinguished by his taste in architecture). Westminster Bridge is 1220 feet in length, and 44 feet in width, having a commodious foot-path, seven feet broad, on each side. It consists of thirteen large, and two small arches, fourteen intermediate piers, and two abutments. (See *plate* XVI.) The length of each abutment is 76 feet; the opening of the smaller arches is 25 feet each; the span of the first of the larger arches, at each end, is 52 feet; of the next, 56 feet; and so on progressively, increasing four feet at a time, to the centre arch, of which the span is 76 feet. The piers of the middle arch are each 17 feet thick, containing 3000 cubic feet, or nearly 200 tons of solid stone. The others decrease equally one foot on each side; every pier terminating with a saliant right-angle against the stream. The arches are semi-circular, and spring from about the height of two feet above low-water mark, leaving a free water-way of 870 feet. The size and disposition of the materials are such, that there is no false bearing, nor a false joint in the whole structure, but they are not of a durable kind. The foundations were laid by means of caissons, (see *art.* 68,) and one of the piers sunk, owing to being undermined by removing sand out of the river. The bridge was opened for passengers in 1750, and cost £218,800. The engineer was M. Labelye, and Mr. James King directed the execution.

100. About ten years after Westminster Bridge was completed, another was begun, at a mile lower down the river, known by the name of BLACKFRIARS' BRIDGE; designed by

Mr. Robert Mylne: it consists of nine arches, of an elliptical form, of which the middle one is one hundred feet in span, and the breadth across the bridge is forty-three feet six inches. (See *plate* XVI.) The whole length of the bridge, from shore to shore, is 995 feet, the breadth of the carriage-way is 28 feet, and that of the foot-path, seven feet, on each side. The centre arch is 100 feet span, and the four arches on either side decrease gradually towards the shore, being 98, 93, 83, and 70 feet respectively, leaving a water-way of 788 feet. The upper surface of the bridge forms the segment of a very large circle, guarded on each side by an elegant open stone balustrade. Over each pier is an open recess, or balcony, supported by two Ionic columns, with pilasters, which rest on a circular projection from the pier above the high-water mark. Each extremity of the bridge is rounded off to the right and left in the form of the quadrant of a circle, which renders the access commodious and agreeable. The arches being elliptical, and of wider span than those of Westminster, the bridge, of course, has a lighter appearance, but the Ionic columns are not in good taste; nevertheless it is a work of very great merit, and will stand a comparison with any other constructed in the same age. It was finished in 10¼ years, and cost £152,840.

It will be an advantage, before we proceed further with the description of bridges, to give the most important points of the theory of the art, in order that the reader may see its application more clearly.

Theory of Bridges.

101. In the THEORY of BRIDGES we have first to examine the nature of *equilibrium* and stability; as, by a proper knowledge of, and attention to, this important subject, the beauty and strength of bridges are to be secured.

The celebrated Dr. Hook proposed, as a proper form for an arch, the curve into which a rope or chain would arrange itself, if suspended at the two extremities by pins or nails fixed in a wall; this curve is commonly called the *catenarian curve*, the properties of which have been investigated by different mathematicians.

102. If a chain, or string of beads, equal in size and weight, be suspended at its extremities by two pins or nails, it will form itself into the curve line called the catenary. Suppose that this curve could be turned steadily round, without change of form, till it obtained a position in which the lowest point became the highest in the same plane; then all the beads in the arch would, by gravity and equal pressure, retain the same position; and, consequently, the arch formed will be the catenary. This arch, however, would support no weight, a mere breath being sufficient to destroy the equipoise.

103. But, if we suppose the beads, in place of being small globes or spheres, to become pieces of a cubical form, equal in height to the diameter of the globes, and retaining the same position, the stability of the arch would be considerable, hence we see that depth of arch gives stability. The arch is now formed of a mass of truncated wedges, arranged so that the cate-

narian curve passes through their centres, and it is for this ease the proper curve of equilibrium; therefore, when the stones are all of the same weight and size, this curve is the only one proper for arches; but, arches not being in any case in practice of this equable form and weight, but must have their haunches filled up, a level or slightly inclined roadway, and parapets, we must investigate the effect of other dispositions of the weight.

104. Suppose it be required to determine the form of an aren, of a given span and height, proper to carry a road-way of a given form.

Let the proposed span be marked horizontally, on a vertical plane of any substance that may answer the purpose; bisect the span by a perpendicular directed downwards, and equal to the given height of the centre of the arch-stones; from the extremities of the span suspend a rope or chain, so that its middle point may be a little below the point marking the intended height of the arch; divide the span into any number of equal parts, and at the points of division raise perpendiculars cutting the suspended chain in particular points; from these points suspend pieces of chain, so adjusted that their ends may meet the line of road-way: and it may be observed that, as those which hang near the haunch bring it down, the crown will rise to its proper position. If the sum of the small chains has, to the large one suspended from the extremities of the span, the same ratio that the material to be filled into the haunches has to the whole weight of the arch-stones, this will be the exact form of the middle of the arch required to support the given road-way; and, by setting off the depth of the arch equally on each side of this line, it gives the curve of the under side of the arch.

105. The curve of equilibrium is, therefore, an imaginary line, and ought to pass through the centre of the arch-stones, and not form the soffit, as the early authors on this subject have stated; for if the curve of equilibrium touches the intrados of an arch of any kind, the compression at the surface must be at least four times as great as if it remained in the middle of the arch-stones, and still greater than this, if it pass ever so little out of the ring of the arch-stones in any part of the arch, for then the arch cannot stand, except by the cohesion of the mortar, which ought not to be depended on.

The passage of the curve of equilibrium through the middle of each block is all that is necessary to insure the stability of a bridge of moderate dimensions and of sound materials, and the strength of an arch is not increased, like that of a frame of carpentry, or of a beam to support a weight by an increase of its depth in preference to any other of its dimensions; but a greater depth gives it a power of effectually resisting a greater extraneous force from the presence of any occasional load on any part of the structure, but the magnitude of such a load is seldom very considerable, in proportion to the weight of the bridge; the breadth of the arch increases with its weight, and must be arranged for convenience of passage, and the depth will be sufficient when the stress on each square foot cannot possibly exceed one-eighth part of the pressure which would crush the material used for the arch-stones, or that load the material bears with safety. (See *art.* 45, 48, and 53.)

106. The pressure increases from the crown towards the abutments, and may be found for any point by drawing a line parallel to a tangent to the curve of equilibrium at that point in this manner. On a vertical line, (*fig.* 3, *plate* XIX,) take any length *c b* by a scale of equal parts, and from *c* draw a line parallel to the tangent to the arch at the springing, and from *b* draw a horizontal line, these will meet in the point *a*, then as *ab* : *ad* : : pressure at the crown : the pressure at the point where the tangent is drawn.

Also if *ac* be parallel to the tangent at the abutment, then *cb* : *ab* : : weight of the semi-arch : pressure on the arch-stones at the crown.

107. The joints ought to be perpendicular to the curve of equilibrium, for if the pressure at each joint be not exactly perpendicular to the joints of the arch-stones, it cannot be resisted without friction, and the parts may slide on each other if they be oblique to the curve: this, however, is an event not likely to occur in practice. But when the curve, representing the general pressure on any joint, passes beyond the limits of the arch-stones, the joints will open at their opposite ends, unless they be held by a very firm cement, and the structure may wholly fall, and if it continue to stand it will be in another form.

108. Having given these principles for the form, stability, and strength of an arch, it only remains to consider the effect of the arch on piers, or abutments. A pier must be considered as an increase in the weight of an arch of sufficient magnitude to cause the curve of equilibrium to fall within its base. Let the centre of the abutting joint be *b*, (*fig.* 6. *pl.* XIX,) and draw *bc* a tangent to the curve of equilibrium at that point, and *ba*, a horizontal line, and *ad* a vertical line from a point *d* as far within the base of the pier as half the depth of the arch-stones; then as *ac* : *cd* : : weight of semi-arch : weight of the pier, and this condition is essential to the stability of the arch.

109. If it be an abutment, the joints should be perpendicular to the line *bd*, in order that they may have no tendency to slide; and the resistance of abutments is generally much increased by prolonging the side walls (called wing-walls).

110. The practical application is rendered much easier by means of algebraic formulæ.

Let w = the weight of a foot in breadth of the arch;

h = the whole height of the abutments or pier from its base;

= the mean thickness of the abutment or pier, the thickness at the base should be greater by half the depth of the arch-stones;

x = the height from the base to the springing;

a = the angle the tangent of the curve forms with the horizon at the springing;

s = the weight of a cubic foot of the stone-work of the pier.

Then hts = the weight of the abutment or pier, and $t \times tan\ a = ac$; (*pl.* XIX, *fig.* 6;) hence $t \times tan\ a : x - t \times tan\ a : : w : hts = \frac{w(x - t \times tan\ a)}{t \times tan\ a}$; consequently $t = \sqrt{\frac{wx}{hs \times tan\ a} + \frac{1}{4hs^2}} - \frac{1}{2hs}$; and, sufficiently accurate for practice, $t = \sqrt{\frac{wx}{hs \times tan\ a}}$.

111. Also if f = the pressure a square foot of stone bears with safety (*art.* 45-53), or one-eighth of the force which will crush the stone; d its depth in feet; and w the whole weight of the semi-arch one foot in thickness, then, $\frac{w}{tan\, a} = df$; or $\frac{w}{f\, tan\, a} = d$ = the depth of the arch at the crown, and $\frac{w}{f\, sin\, a} = d$ = the depth at the abutment; when the arch is of the proper figure. In the description of the plates we will show the application of these equations; and now proceed to give a brief view of the fall of water under the arches of a bridge, it being necessary to pay some attention to this, in designing the edifice.

112. It is known that, if the same quantity of water, that flows in an open extended channel, have to pass through a space any way contracted, it rises above the general level; and, consequently, has the velocity of its current increased. The piers of a bridge form obstacles in the way of running waters, and in proportion as they contract the channel, the water will rise above the usual level, and the rapidity of the current be increased; but the investigation of the law of increase, agreeing to a given contraction, would occupy too much room for our present purpose, and would, also, be too refined a speculation for this work; we shall, therefore, present two tables which may be of considerable use to men of practice, as the effect of different contractions is brought at once under his view.

We do not pretend to say, that the tables are complete, yet they will be found to answer many useful purposes; and, in order that they might be as perfect as possible, we have given one for the velocity, and the other for the rise the obstruction will produce in the level of the river's surface, for a space equal to the breadth of the bridge. The depth has to be attended to, in discovering the velocity; but we will not enter into these delicate circumstances, as the data cannot always be obtained with similar exactness.

113. We shall now give an example to show the use of the tables.

Suppose it were required to build a bridge over a river, 100 feet wide, and velocity three feet per second; but the abutments and piers together reduce the water-way to 75 feet, that is, diminishing the original width by one-fourth.

Look in the upper table, opposite to 3 feet, and under the obstruction $\frac{1}{4}$, and 0 135 will be the head found; this is about 1·6 inch, and therefore is not objectionable; and, by the lower table, the velocity under the arch will be 4·2 feet per second; which the bottom should be capable of bearing.

The effects of accidents to which rivers are liable may be discovered by the second table.—By inspection, it will be seen that, when the velocity is 10 feet per second, or above it, the power of the inundation is sufficient to carry away every thing before it, except the hardest primitive rocks, while firmly united in their natural beds. The numbers in the latter part of the table therefore show that, in fact, such contractions are impracticable.

114.—*The* Rise *of* Water *produced by* Obstructions *to a* Current, *when they are formed to divide the Stream, as Piers with Pointed Sterlings, &c.*

VELOCITY.		DESCRIPTION OF RIVERS.		OBSTRUCTIONS.								
Per Second. Ft. In.	Per Hour. Miles.	The Current usually termed.	The Bottom which just bears the effect of such Rise.	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
				Head of Water produced at the Obstruction, in Feet.								
$\frac{1}{4}$ or 3	$\frac{1}{6}$	Dull,	Oaze and Mud,	·0003	·0004	·0004	·0006	·001	·0014	·0033	·0067	·0162
$\frac{1}{2}$ or 6	$\frac{1}{3}$	Gliding,	Soft Clay,	·0011	·0014	·0017	·0023	·004	·0058	·0133	·0267	·0647
1	$\frac{1}{2}\frac{5}{2}$ or $\frac{2}{3}$	Smooth,	Sand,	·0045	·0056	·0069	·0091	·015	·0231	·0532	·1069	·259
2	$2\frac{1}{3}$	Uniform Tenors,	Gravel,	·0182	·0225	0276	·0364	·060	·0924	·2128	·4276	1·036
3	$2\frac{1}{2}\frac{1}{2}$	Ordinary Freshes,	Pebbles, Shivers, and Shingle,	·0409	·0507	·0621	·0819	·135	·2079	·4788	·9621	2·351
4	$2\frac{6}{1}\frac{6}{1}$			·0728	·0902	·1104	·1456	·240	·3696	·8412	1·7104	4·144
5	$3\frac{9}{2}\frac{9}{2}$	Extraordinary Floods,	Boulders and Soft Schistus,	·1137	·1410	·1725	·2275	·375	·5775	1·3200	2·672	6·475
6	$4\frac{1}{1}\frac{1}{1}$	Rapids,	Stratified Rocks,	·1638	·2030	·2484	·3276	·540	·8316	1·9152	3·848	9·324
10	$6\frac{9}{1}\frac{9}{1}$	Torrents and Cataracts	Indurated Rocks,	·4550	·5640	·6901	·9100	1·500	2·3100	5·32	10·69	25·9

VELOCITY.		DESCRIPTION OF RIVERS.		OBSTRUCTIONS.								
Per Second. Ft. In.	Per Hour. Miles.	The Current usually termed.	The Bottom which just bears such Velocities.	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{8}$	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$
				Velocity produced at the Obstruction, in Feet per Second.								
$\frac{1}{4}$ or 3	$\frac{1}{6}$	Dull,	Oaze and Mud,	·28	·29	·30	·32	·35	·394	·52	·7	1·05
$\frac{1}{2}$ or 6	$\frac{1}{3}$	Gliding,	Soft Clay,	·56	·58	·60	·63	·70	·787	1·05	1·4	2·1
1	$\frac{1}{2}\frac{5}{2}$ or $\frac{2}{3}$	Smooth,	Sand,	1·13	1·16	1·20	1·26	1·40	1·575	2·1	2.8	4·2
2	$2\frac{1}{3}$	Uniform Tenors,	Gravel,	2·27	2·33	2·40	2·52	2·80	2·75	4·2	5·6	8 4
3	$2\frac{1}{2}\frac{1}{2}$	Ordinary Freshes,	Pebbles, Shivers, and Shingle,	3·40	3·39	3·60	3·78	4·20	4·325	6·3	8·4	12·6
4	$2\frac{3}{1}\frac{3}{1}$			4·54	4·66	4·80	5·04	5·60	6·5	8·4	11·2	16·8
5	$3\frac{9}{2}\frac{9}{2}$	Extraordinary Floods,	Boulders and Soft Schistus,	5·68	5·83	6·00	6·30	7·00	7·875	10·5	14·0	21·0
6	$4\frac{1}{1}\frac{1}{1}$	Rapids,	Stratified Rocks,	6·81	6·99	7.20	7·56	8·40	9·45	12·6	16·8	25·2
10	$6\frac{9}{1}\frac{9}{1}$	Torrents and Cataracts	Indurated Rocks,	11·36	11·66	12·00	12·60	14·	15·75	21·	25·9	42·0

115. The next subject which claims our attention is the Water-breakers, or, what the workmen call *Sterlings*, being the extremities of the piers which meet and divide the water in its course. The preceding table supposes them to be rounded, or pointed, but if they be square and abrupt, the contraction produces a greater velocity by one-eighth, and the head is about $1\frac{1}{2}$ times the head for rounded piers, and, consequently, very objectionable in navigable rivers.

The opinions of engineers respecting the proper form of this part of a bridge are various, some contending for one form, and some for another; but, it is obvious that, the form which divides the water with least resistance, and least contracts the water-way, must be the best; if, at the same time that these advantages are attained, it retains sufficient strength to support the structure.

The right-angled isosceles triangle was formerly employed by some bridge-builders as a form the most suitable; this opinion arises from the consideration of the right-angle being the strongest of all others; that is, if two bodies meet each other at right-angles, they will overcome a greater resistance than they would do at any other inclination. Others contend for a form composed of two arcs, containing each 60°, described from the two angles of the pier, and meeting each other in the line dividing the water: sometimes a semi-ellipse, described on a conjugate equal to the width of the pier, is used; and, not unfrequently, others of the conic sections, or some whimsical figure that pleases the fancy of the architect.

Those who adopt the right-angle, erroneously contend that it divides the stream best; those who use the semi-circle and semi-ellipse, consider that they are the best calculated to resist the shock of a loaded barge, or other floating body, that may come upon them, and that the Gothic arches combine the advantages of both: we have already observed, that the form must be adapted for dividing the stream, and allowing the water to pass most freely; and it obviously should not be pointed so as to be dangerous to navigation.

Illustration of the Principles of Bridges.

116. We commence our illustration of the principles of Bridges with the magnificent edifice which bears the triumphant appellation of Waterloo Bridge; a work not less pre-eminent among the bridges of all ages and countries than the event which it commemorates is unrivalled in the pages of ancient or modern history.

It consists of nine elliptical arches, each of 120 feet span, and 35 feet rise, (see *plate* XVI,) the piers are 20 feet thick; and the water-way is 1080 feet. The road-way is 28 feet wide, with a foot-pavement of granite, of 7 feet width on each side. The arches and piers are built of large blocks of Cornish granite, with short reversed arches in each pier for the principal ones to abut against. The spandrils over the haunches are filled in with longitudinal walls of brick, with spaces between them, which are covered over with strong pieces of sand-stone to form the road-way upon. These hollow spaces lighten the stress on the bridge considerably; and are provided with proper outlets to prevent water collecting in them. The arch-stones

were so well worked and truly bedded together, that the settlement at the crown did not exceed two inches on removing the centring.

The roadway is level, and the cornice is supported at the piers by massive Doric columns; the parapets are open balustrades, the balusters of Aberdeen granite, but the rest of the apparent parts of the bridge are of Cornish granite, and not of a very good quality.

117. To apply our formula (*art.* 110) to this case, the weight of a foot in breadth of the semi-arch of the bridge, or $w = 112{,}500$ lbs.; the whole height of the abutment, or $h = 48$ feet; the height of the point where the curve of equilibrium cuts against the abutment, or $x = 22$ feet; the tangent of $a = \cdot 83$; and the weight of a cubic foot of stone 150 lbs.; consequently, $\sqrt{\frac{112500 \times 22}{48 \times 150 \times \cdot 83}} = 20{\cdot}4$ feet. To this we have to add half the depth of the arch-stones, which are about 7 feet at the springing, making about 24 feet for the least thickness at the base of the abutment. Hence we see that the piers, being only 20 feet, are not sufficient to resist the push of the arches. The thickness at the base as executed is 30 feet, which is not more than a sufficient allowance for a foundation on piles.

118. To find the proper depth for the arch-stones at the crown we have $w = 112{,}500$ lbs., tangent of $a = \cdot 83$; and by (*art.* 45) the pressure a square foot of Cornish granite will bear is 114,000 lbs.; whence the depth in feet is $\frac{112500}{114000 \times \cdot 83} = 1{\cdot}2$ feet; now the actual depth is $4\frac{1}{2}$ feet; a degree of strength which would be sufficient to resist any change of figure, by yielding at the abutment, which does not cause the curve of equilibrium to quit the ring of arch-stones. For it is obvious that the stress is on the back part of the abutment, and if that part be not rendered as firm as solid rock, it must be compensated for by increasing the area of the base in proportion to its want of firmness; otherwise some degree of change may take place.

Waterloo Bridge was built under the direction of the late Mr. John Rennie.

119. The Bridge of Neuilly, over the Seine at Paris, which was built by the celebrated French engineer, Perronet, is our next example, and the construction is exhibited in Plate XVIII.* It is composed of five elliptical arches of 128 feet span, which spring from the low water line; the piers are only $13\frac{1}{2}$ feet; and the bridge is founded on piles, the platform on which the stone-work commences being $7\frac{1}{2}$ feet below the level of low water. The ends of the piers are circular, and the arches are splayed towards the springing, so as to render the apparent form of the arch a flat segment of a circle, see *fig.* 1, and the section, *fig.* 3. In each of the abutments there is a small arch for the towing-path; the road-way over the bridge is level, and the ascent from the sides is effected by inclined roads, as shown by the section, *fig.* 3. and plan, *fig.* 2. The width of the carriage-way is 31 feet, and the foot-paths are each 6·6 feet.

During the setting of the arch-stones of this bridge, the centre changed its form considerably, and its rate of settlement, before the key-stone was inserted, was 3 inches in 24 hours; hence we have shown its construction in *fig.* 5, in order that a construction possessing so little

* This plate has been erroneously numbered XIX. in some of the numbers first published.

resistance to change of form may be avoided.* A still more dangerous change took place on removing the centring; and, to observe it, straight lines were traced on the face of the arch before the centring was struck, as shown at *ab, bc, cd,* (*fig.* 4.) and their position, in regard to fixed points at the extremities, were ascertained. The lines became curved, as shown by the curved lines by the side of the straight ones on the figure. The joints opened at the back of the arch at the haunches, and they opened at the under-side at the crown, showing that the arch was not properly designed. The radius of curvature at the crown was intended to be 160 feet, but the arches settled so as to render the radius 250 feet; and the stress on the arch is nearly as the radius.

The depth of the key-stone is 5·3 feet, and the arches are constructed of Saillancourt-stone, which, it has been ascertained by experiment, will bear a pressure of 30,000 lbs. on a square foot with safety. Therefore, the weight of a foot in breadth of the semi-arch being about 61,000 lbs., and $tan.\ a = \cdot 44$, we have (by *art.* 111) the depth $= \frac{61,000}{30,000 \times \cdot 44} = 4 \cdot 6$ feet; showing that the arch was of depth sufficient for its first form, if the centring and abutments had been sufficient to preserve that form.

120. In the last case, the arches had a manifest tendency to sink at the crown and rise at the haunches, but this is not always the case, as will be known from the example we are now about to describe. William Edwards, a country mason, engaged in 1746 to build a bridge across the mountain-torrent, called the Taff, in Glamorganshire, and he erected one of a light and elegant structure, with three arches; but soon after the completion a flood occurred, and it failed from want of water-way. Edwards having given security for the bridge remaining a safe means of passage for seven years, he began another of one arch only, the span of which was 140 feet, with a rise of 35 feet, being part of a circular arch of 175 feet diameter. The arch was finished, and the parapets only remained to be done, when, through the haunches being too heavy in proportion to the load at the crown, the crown rose upwards till the haunches fell into the river. Edwards saw the cause of the failure; and, with the true spirit of a Briton, began a third bridge, of a single arch, of the same dimensions as the second, and formed a series of circular apertures through the spandril parts of the haunches, increasing in diameter towards the abutments; this expedient reduced the weight of these parts, so as to preserve the balance and stability of the structure; it was completed in 1756, and remains a monument of the skill of William Edwards, and one of the finest illustrations of the theory of Bridges.

121. The bridge across the Severn, at Over, near Gloucester, which was designed and executed under the direction of Mr. Telford, the President of the Institution of Civil Engineers, is the next example. (See *plate* XIX.) It consists of one elliptical arch of 150 feet span, and 35 feet rise; it is splayed at the haunches in the manner of the bridge of Neuilly; the apparent arch being a flat segment of a circle of 246 feet radius, and the water-way is further increased

* For the construction of Centring for Bridges, see our Practical Carpentry, *art.* 102, et seq.

by two small arches, one through each abutment. The roadway for carriages is 17 feet wide, and there is a foot-path of 4 feet on each side; the whole breadth of the bridge being 27 feet, including the parapets. The roadway is supported over the spandrils by longitudinal walls of brick, with covers of stone for the cavities (see *fig.* 2 and 4.) The depth of the arch, at the crown, is 4½ feet, and it is constructed of an excellent species of sand-stone from the Forest of Dean. The weight of a foot in breadth of the semi-arch is about 140,000 lbs.; the tangent of the curve of equilibrium, at the abutment, is ·58; and the stone will bear 90,000 lbs. per square foot; therefore, by the rule, (*art.* 111.) $\frac{140{,}000}{90{,}000 \times {\cdot}58} = 2{\cdot}7$ ft. for the depth, when there is no change of figure to be apprehended, and this is only five-eighths of the actual depth.

The abutments are 21⅔ feet, with two walls, 7 feet thick, extending 42 feet from each (see the plan, *fig.* 5); these are much more effective than the same quantity of stone-work in a solid mass, besides forming the support of the continuation of the roadway. By the rule, we easily determine that the mean thickness of a solid pier should be 36·1 feet, and as much more than an equivalent mass of matter is disposed in a better form for resistance, the bridge possesses that excess of strength which ensures durability.

Of the numerous bridges erected under the design and direction of Mr. Telford, this is unquestionably the best; it unites the greatest possible degree of lightness of appearance with an ample provision of strength; and the span is the greatest that has been executed in stone.

122. The masonry of the Suspension Bridge across the Menaï, at Bangor, is our next example, and another of the immense works which Mr. Telford has designed. In common bridges, the stress tends to force the abutments outwards,—in suspension bridges, the tendency is to draw them inwards; and an equivalent degree of firmness of construction is required. From two piers, 579 feet apart, from centre to centre, a roadway is supported by chains of iron over the Menaï Straight, which divides Anglesea from Wales (see *plate* XX, *fig.* 1). On the Anglesea side, the suspension-piers are connected to the shore by four arches in stone, of 52½ feet span; and, on the Caernarvonshire side, by three arches of 52½ feet span. The weight of the masses of masonry forming these arches balances the weight of the roadway, and the chains are further secured behind the abutments, as indicated in the figure. The roadway is at the height of 102 feet above the level of spring-tides, and, consequently, there is a free space of 560 feet in width, and 102 feet in height, for ships to pass. *Fig.* 2, shows part of the plan of the roadway to a larger scale; it consists of two carriage-ways, with a foot-way in the middle between them. *Fig.* 3, is a plan of the other end of the bridge, with part of the roadway, showing the planking and the archways through the suspension-tower. Thus, by the combination of strong chains of tenacious iron, with ponderous blocks of stone, skilfully arranged according to the principles of masonry, a safe and commodious road is formed for the mails and traffic across the sea, which separated the Isle of Anglesea from Wales.

123. The New London Bridge, now erecting on the western side of the old one, and as near to it as was considered safe, is from the design of the late Mr. John Rennie, and executing

under the direction of his sons, Messrs. John and George Rennie, with some variations. The principal parts are of Scotch granite. The bridge consists of five elliptical arches, (see *plate* XVII,) the span of the centre one is 150 feet, and the rise 29½ feet, above the datum, as the level of the high-water mark of the Trinity-House is called; the piers adjoining the centre arch are 24 feet each; the span of the arches next the centre one is 140 feet, with a rise of 28½ feet above the datum, and piers of 22 feet each. The span of the arches next the abutments is 130 feet, with a rise of 25 feet above the datum, and abutments of 74 feet each. This makes the total length of the water-way 690 feet; the length between the abutments 782 feet; and the total length, including the abutments, 930 feet. The width of the carriage-way is to be 36 feet, and the width of the bridge, to the outsides of the parapets, is 56 feet.

CHAPTER VI.

OF THE CONSTRUCTION OF DOMES, GROINS, AND SPIRES.

124. The Construction of a Dome is less difficult than that of an arch, because the tendency which each part has to fall, is not only counteracted by the pressure of the parts below, but also by the resistance of those on each side; hence a dome may be erected, without the expensive centring which an arch requires, and it may also be left open at the top, or without any key-stone. Many of the large domes have nevertheless failed, or cracked, so as to create alarm, and generally in consequence of the inadequacy of the supporting walls or piers.

The masonry of domes differs from that of arching, in the figure of each voussoir, which must fit the void in a sphere instead of a cylinder. If a dome rises nearly vertical, with its form spherical, and of equal thickness, it should be confined by a chain, or hoop, as soon as the rise reaches to about $\frac{11}{14}$ths of its whole diameter, in order that the lower parts may not be forced out: but, if the masonry be diminished in thickness as it rises, this precaution will not be necessary.

125. *The dome of the antient Pantheon*, at Rome, built by Agrippa, is the oldest and the finest example. (See *plate* XXI.) It is the largest vaulted edifice constructed by the antient Romans; the plan is circular, the interior diameter 142 feet, and it is cylindrical to the height of 72¼ feet, with a wall 23 feet in thickness; but the wall has so many large niches and deep recesses, that the mass is not more than equivalent to that of a wall one-third of the thickness; while the advantage in disposition is evident. The dome itself is internally a hemisphere, with an opening at the top 29 feet in diameter; the thickness is 4 ft. 10 in. where it joins the platform round the aperture, 5 ft. 2 in. just above the last set-off, and 17 feet where it joins

the circular wall which supports it; but the mass of the dome is diminished by five ranges of deep sunk caissons. The ribs between the caissons are of brick, the pannel part of tufa and pumice stones in small pieces.*

The construction of the cylindrical portion is not less judicious, it is of brick and filled in with rubble-stone, but at every four feet in height a bond of brick-work is formed of bricks two inches thick and two feet square; the discharging arches also consist of two series of these bricks, and the angles and faces of the wall are built of triangular bricks.

If we attentively examine the nature of this work we find the supporting part to consist of piers connected by a continued inclosing wall, which gives the greatest degree of strength at the base, at the place where it is required to resist a tendency to overset. The dome consists of ribs and pannels; the depth of the ribs gives stability, and the pannelled spaces are filled in with as much lightness, both in regard to material and thickness, as was consistent with the proper degree of strength. In this remarkable structure, every artifice which theory indicates is employed; and the most refined works of the Gothic builders, though so different in form, are the same in respect to principles; the supports in both are piers connected by an inclosing wall; and the vaultings of deep ribs filled in between with light pannels. The Pantheon has now existed nearly nineteen centuries; and its fine portico has been admired by architects with more or less of paltry criticism, but the scientific skill necessary to construct such an edifice, in the absence of an example to imitate, is a rare acquirement, not often possessed by above one in an age. On the restoration of the arts in Italy, many attempts were made to imitate the dome of the Pantheon; but the skill of the architect was, in general, insufficient to ensure success.

126. Anthemius, a Greek architect, was selected by the Emperor Justinian, for erecting a dome to the church of St. Sophia, at Constantinople, the church itself was to be in the form of a cross, and vaulted with stone; the dome he attempted to raise on the heads of four piers, of about 115 feet high, and at the same extent from each other, and strengthened by four buttresses. The buttresses were solid masses of stone, extending, at least, ninety feet from the piers to the north and south, so as to form the side walls of the cross. These effectually secured the piers from the thrust of the two great arches of the nave which supported the dome. But, when the dome was finished, and had stood a few months, as there was no provision against the thrust of the great north and south arches, the two eastern piers, with their buttresses, gave way; and the dome and half-dome fell in. On the death of Anthemius, Isidorus, another Greek, succeeded to the work, and, having filled up some hollows to strengthen the piers on the east side, again began to raise the dome; but, while one part was building, another part fell in. It was now found that the pillars and walls of the eastern semi-circular end were too much

* It is said, that when the walls were raised to the springing of the dome, the interior was filled with earth to turn the dome upon; and that to induce the people to remove the earth money was strewed among it, a mound being still pointed out by the common people of Rome as the place to where the earth was removed; but the story is improbable, for the scientific skill so well developed in the design of the edifice could not have had a difficulty in contriving a centre, and one of earth would have settled so as to be useless.

shattered to give any resistance to the push which was directed against them; and therefore several clumsy buttresses were erected on the eastern wall of the square which surrounded the Greek cross. These were roofed in, so as to form a kind of cloister, and lean against the piers of the dome, and thus oppose the thrust of the great north and south arches. The dome was now turned for the third time; and though it was extremely flat, and, except the ribs, roofed with pumice-stone, it was soon found necessary to fill the whole, from top to bottom, with arcades, in three stories, to prevent the dome falling a third time. Thus a dome, which was intended to be a beautiful specimen of architecture, was rendered a mis-shapen mass of deformity and an example of ignorance, which should warn the architect not rashly to undertake what he has not sufficient science, in a proper manner, to perform.

127. Since that time, domes have been erected in various parts of Europe, and some that display every requisite of beauty and strength, peculiar to this species of building. St. Peter's, at Rome, an elliptical dome, 139 feet in diameter, is a superb specimen, but not without defects, which have shown that its architects knew better how to distribute its supports for grandeur of effect, than for firmness and durability, the dome having many cracks from the unequal settlement of its supports.

128. The inner dome of St. Paul's, at London, is also elliptical, and open in the centre; it is 112 feet in diameter, and still continues perfect. The lantern is supported by a conical vault of brick-work, a figure admirably adapted for supporting an immense load on its summit; but the outer dome is formed by wooden framing.*

129. The dome of the church of St. Genevieve, including the peristyle on which it rests, is a beautiful specimen as to form and composition. The peristyle is formed by fifty-two columns of the Corinthian order, each about fifty feet high, completely insulated, and standing on a circular pedestal. Above the cornice of the peristyle, the dome arises in a beautiful curved line to the top, on which is formed a pedestal and gallery. But, when the dome was raised, the columns composing the interior began to sink with the weight; and some of the shafts of the columns decorating the interior, which consisted of four naves, with the lantern and dome over them, began to fracture at the joinings; this defect was removed by walling up the inter-columniation at the four quarters of the screen, which thus preserved from dilapidation one of the boldest monuments of genius.

130. The following table gives the interior diameter, the height of the top of the dome from the floor of the edifice, and the date of construction, when known, for some of the most celebrated works of the kind in Europe.

* The church of St. Genevieve has three vaults, all in stone, but then it is only 67 feet in diameter, with the vaults of such improper forms that they will not sustain the weight it was intended to place on them.

TABLE *of the principal* DOMES, *arranged according to their Interior Diameters.*

NAME OF THE DOME.	PLACE.	Interior diameter in feet.	Height of the top from the floor in feet.	Date of Erection.
1. The dome of the Pantheon	Rome	142	143	B.C. 18
2. The dome of Saint Peter's	Rome	139	330	A.D. 1580
3. The dome of Santa Maria delle Fiore	Florence	139	310	1436
4. The dome of the Temple of Apollo		120		
5. The dome of Saint Sophia	Constantinople	115	201	537
6. The dome of Saint Paul's	London	112	215	1710
7. The dome of the Baths of Caracalla	Rome	112	116	217
8. The dome of the Temple of Diana	Puzzuoli	98	78	
9. The dome of the Mosque of Achmet		92	120	
10. The dome of the Chapel of Medicis	Florence	91	199	1636
11. The dome of the Temple of Venus	Puzzuoli	87	77	
12. The dome of the Baptistery	Florence	86	110	
13. The dome of the Church of the Invalids	Paris	80	173	1704
14. The dome of Minerva Medica	Rome	78	97	0
15. The dome of the Baths of Diocletian	Rome	74	83	302
16. The dome of the Church of Madonna della Salute	Venice	70	133	1640
17. The dome of the Temple of Mercury		68		
18. The dome of the Church of Saint Genevieve	Paris	67	190	1790
19. The dome of the Superga	Turin	64	128	1731
20. The dome of the Cathedral of Milan	Milan	57	254	1425
21. The dome of the Church at Sienna		57	118	1250
22. The dome of the Church of Val de Grace	Paris	55	133	1660
23. The dome of the Church of Saint Vital	Ravenna	55	91	547
24. The dome of the Church of Saint Marc	Venice	44	----	984
25. The dome of the Church of the Sorbonne	Paris	40	110	1653
26. The dome of the Church of Saint Maria	Ravenna	36	61	530

Theory of Domes.

131. In domes the same general principle applies as in arches, (*art.* 105,) the curve of equilibrium, or the resultant of the pressures at any point, should fall within the thickness of the dome or its supports; otherwise we might as well try to support a weight by a single pillar placed in any other position than in the vertical line immediately under its centre of gravity.

132. When the weight of the dome is equally distributed over the area, then the curve of equilibrium is a cubic parabola; and if one-sixth part of the weight supported be multiplied by the diameter, and the result divided by the rise, the quotient is the horizontal thrust tending to separate and overset the supporting wall.

133. When the weight increases from the centre to the circumference in proportion to the distance from the centre, then the curve is a biquadratic parabola, and one-eighth part of the weight should be taken instead of one-sixth part.

134. It also may be proved, that the horizontal thrust of the dome will be wholly counteracted by a resistance to tension in the circle, equivalent every where to one-sixth of the horizontal thrust; and, when this strain is amply provided for, either by the bond and substance of the walls at the springing, or by chains of iron, the dome will be secure at whatever height from the ground it may spring, if the vertical walls or pillars be sufficiently so to resist the weight upon them.

135. The plan of a dome is usually a circle, and this is the most perfect figure for the purpose; but any regular polygon may form the base of a dome, whether octagon, decagon, &c. they do not, however, possess the same property of resisting change of figure which belongs to the circular base.

136. If the lateral or horizontal thrust is to be resisted by the weight of the supporting wall or piers, so as to be sufficiently strong without the connection obtained by binding the parts together in a continued circle, then, the rule (in *art.* 110) applies to this case, as well as to arches, where the whole weight of the dome divided by the circumference of the supporting wall, or the sum of the breadth of the piers, in feet, is inserted for w, in finding the thickness.

137. In like manner, by finding the weight w on each foot of circumference, the depth of the dome may be found, which renders it of sufficient strength, either at the abutments or at the crown, (by *art.* 106 and 111,) for when the connection of the parts is left out of the calculation, as a proper reserve of strength for duration, the arch and dome are dependent on the same principles.

Of Groined Vaulting.

138. A long rectangular space may be covered with a continued arch, called a vault, but so heavy a covering, destitute of variety, had little chance to please the taste of men, who, having seen the finest works of antiquity, were desirous of excelling them, if possible, particularly in the construction of the peculiar form that had been selected for Christian churches. The plan being a cross, the object was to find a graceful and varied form of covering, in which the profound science displayed in the Roman Pantheon should, at least, be equalled: for that work was evidently considered the master-piece of the age.

139. A vault, or continued arch, consisting of deep ribs, with thin pannels between, might first suggest itself; and such a construction has been employed in both vaults and bridges, the

old Gothic bridge at Durham, called Framwell-gate Bridge, now being altered and widened under the direction of Mr. Bonomi, architect to the county of Durham, is one of the finest examples of the kind. On this subject we have only to remark that, in a bridge, deep ribs expose a much greater surface of stone to decay, and the experience of many ages has shown that a plain soffit is better; but we see no difficulty in obtaining the advantage which the Gothic bridge has in real lightness and stability, without exposing more surface to the weather than the common method. When applied as a vault, the continued arch required continued thick walls for abutments, and these were too heavy, expensive, and tasteless for the spirit of the age.

140. Vaults, supported by piers or pillars, were sometimes executed by the antient Romans; but there is a degree of formal clumsy heaviness about them, which is universally felt, and often censured; the Gothic vault, on the contrary, commences at the base of the pillars which support it, and these being carried perpendicularly to a proper height, bend over and spread to form the ribs of the vaulting; no interrupting entablature breaks the connection between the pillars and the ribs of the vault; hence that lightness of effect, with apparent as well as real strength and fitness, which characterize the stone roofs of our cathedrals; and show that these works were the production of men having a knowledge of what is most profound in the science and practice of building, and a boldness in execution of which classic antiquity furnishes no example; neither has it descended to our times; the art has fled, but left for our instruction,—

> "Her pendant roof, her windows' branchy grace,
> Pillars of cluster'd reeds, and tracery of lace."

141. In a dome, if the part supported be divided into triangular portions, the base of each triangle is at the supporting wall;—in a groined vault divided into triangles, the vertex of each triangle is at one of the supporting piers;—in an arch, instead of triangles, we have parallelograms. But, notwithstanding this diversity in the distribution of the load to be supported, the same general principles apply, for they are but different cases of the same mechanical problem.

142. When the weight of a groined vault is equally distributed over the area it covers, the curve of equilibrium is a semi-cubical parabola; and the horizontal thrust of a part comprehended between two angle-ribs, is one-third of its weight multiplied by the span of the arch, and the result, divided by its rise, gives the thrust tending to overset the pillar or pier in the direction of the body-rib of the compartment.

143. If the weight be distributed so as to increase in proportion as it approaches the support, then the curve of equilibrium will be a common parabola, and one-fourth of the weight of a compartment should be taken instead of one-third, but in other respects the horizontal thrust is to be found as in the last article.

144. The parts of the groin which are on opposite sides of the pier balance each other, and it is usual to make the piers only of sufficient magnitude to support the load; but the piers are so connected, by the side-walls between them, that a failure from a pier being deprived of

one of its arches is scarcely possible. In groins, as in domes, the central part may be removed, or may support a pendant load of considerable weight.

145. The earliest examples of vaulting with stone in this country were executed in the reign of Henry III., consisting of cross-ribs springing from corbels in the side-walls, with the pannels filled in with lighter materials; and, about the reign of Edward III., cross-springers were introduced with more frequent and complicated intersections, covered with carved orbs and rosettes, and the arches were pointed. To this the style of vaulting, called "fan-work," succeeded; at first, from its extreme cost and delicacy, it was confined to tombs, small chapels, and cloisters, but was afterwards applied to roofs of larger buildings. The principal vaulted roofs are collected in the following table.

146. Vaulted roofs constructed in the fourteenth, fifteenth, and sixteenth centuries:—

	Date.	Length.	Breadth.	Height.
Choir of Lincoln Cathedral	1306	200 ft.	40 ft.	82 ft.
Our Lady's Chapel at Ely	1349	100 —	46 —	
Choir of Gloucester Cathedral	1360	140 —	34 —	
Do. of York	1373	135 —	45 —	
Divinity School, Oxford	1480			
Chapel of St. George, Windsor	1508	260 —	65 —	
Do. Henry VII. Westminster	1508			
Do. King's College, Cambridge	1516	289 —	44½ —	81 —
Choir at Windsor Cathedral	1525	138 —	86 —	
Chapel of Christ Church, Oxford	1535	80 —		

This list, short as it is, will enable many of our readers to refer to existing works—

> "Where antient art her dædal fancies play'd,
> In the quaint mazes of the crisped roof."—WARTON.

147. We alluded to the roof of King's College Chapel in our Introduction, (*art.* 3,) and we have chosen it as an example of the fan-shaped groin (see *plate* XXIV). It is 289 feet in length, 44½ feet in width, and 81 feet in height; and divided into rectangles, of which the width is half the width of the body of the chapel; each rectangular portion of the vault resting on four piers.* *Fig.* 2, is part of the plan, including four of the supporting piers with the ribs and tracery of the vault in one part, and the form of the stones as they appear on the upper surface of the vault in the other part. *Fig.* 1, is a section across the chapel, in which one part is from A to B on the plan, the other part from C to D, through the middle of the pier. *Fig.* 3, is a section of one of the ribs to a larger scale, showing the thickness of the ashler work forming the pannels between the ribs. These ribs are 7½ in. deep, and the ashler

* In an indenture, dated 1513, by which I. Wastell and Henry Severick engaged to finish the vaulting in three years, these divisions of the vaulting are called "Severeys," and, on the completion of each severey, they were to have £100., there are twelve of them.

work of the pannels 4½ in. thick. Great as the merit of the designer is, his name is unknown; but its successful execution merits an equal degree of praise, and the names of John Woolrich, Henry Severick, and John Wastell, may be handed down to posterity as the most skilful master-masons of their age and nation.

Of the Construction of Spires.

148. The spires of churches are pyramidal vaults either straight or convex, and generally a little convex; they vary from 6 to 9 inches in thickness, according to the quality of the stone, or the size of the spire. The base is sometimes square, but most frequently octagon; and they are raised from either square or octagon towers.

149. When a spire springs from a square tower, the walls of the tower are gradually increased in thickness towards the point from whence the spire rises, and are formed to the shape of its base; the bond of the work being rendered as perfect as possible, by employing large stones, crossing the joints, and connecting them by cramps run in with lead; sometimes the ring of stones on which the base of the spire rests is further secured by a chain of iron, bedded in the stone, and run in with lead. The bed-joints of the spire itself must be perpendicular to its slant surfaces, and the vertical joints directed to the centre.

In order to illustrate these remarks by examples, we have selected two of the most esteemed spires in England.

150. The spire of Salisbury Cathedral (see *plate* XXI.) is octagonal, and rises from the centre of the square tower, four of its sides resting on the walls of the tower, and the other four on arches across at the angles, at the top of the tower; the wall is five feet in thickness, two of which are occupied by the base of the spire, two by a passage to go round it, and one by the parapet. The wall of the spire gradually diminishes in thickness to about twenty feet above the tower, where it is reduced to nine inches, and is continued of that thickness to the summit. The figure in the plate is one half section, showing the timber-framing within, which is ingeniously contrived, the other half elevation. Externally, the spire is ornamented with ribs up the angles, each of which has two rows of knobs attached to it, and the spire is divided into four nearly equal portions, by bands of tracery, pannels, &c. At the base there are four decorated door-ways to the parapet of the tower. The two uppermost divisions, or stories of the tower, and the whole of the spire, are evidently of later erection than the church, or of the lower story of the tower; the stile of architecture is enriched; and in the forms and ornaments of the pediments, pinnacles, and open parapets, resemble the much-admired crosses raised by King Edward I., and other works erected at the end of the thirteenth century. It seems that the architect of this spire was ambitious to carry its apex higher than any similar building of stone in England; from the ground to the highest point is 404 feet; and though it is not of equal altitude to that of St. Stephen's Church at Vienna, which is 465 feet, nor that

of Strasburgh, which is 456 feet, yet its vast height has rendered it an object of popular wonder, as well as of great curiosity and interest to the architect. To the old tower 387 feet of new foundation was added on the erection of the spire, and several windows were filled up, and ties of iron inserted. A settlement has taken place on the western side; and it appears that, at the cap-stone of the spire, the declination is 24½ inches to the south, and 16¼ to the west. The date of its erection is the end of the thirteenth century.

151. The spire of Litchfield Cathedral is represented on the same plate, and in a similar manner, one half being a section, the other half elevation. It was finished in the middle of the fifteenth century, and it is a good example of an ornamented spire, but we do not think the insertion of windows appropriate, nor that horizontal bands and mouldings improve a spire; they seem to owe their effect to fine proportions rising unbroken from the base to the summit; nevertheless some degree of ornament improves a spire; and the effect of one perfectly plain, ending in a needle-point, may be seen at the church Mr. Nash built in Langham Place.

152. When a spire is an exact pyramid, its arrises, though straight, appear concave to the eye; hence, in construction, they should be slightly convex; and further, it may be proved that where there is not a perfect coherence of the parts, the figure should be convex to be of equal strength in all its parts. We have treated this subject at greater length than we had intended, because, in our eyes, the beautiful spires of some parts of England add much to the interest and effect of the country.

CHAPTER VII.

OF THE CONSTRUCTION OF LIGHT-HOUSES.

153. A LIGHT-HOUSE is a tower of considerable height, with the means of producing light in the top part, or lantern, so as to render it visible to a great distance at sea, to serve as a guide to seamen in steering their vessels in the night-time.

154. Those light-houses which are constructed on the sea-coasts, or on the piers of harbours, present very little difficulty; a round or octagon tower, with a winding stair, and small rooms for the accommodation of the keeper, being the only essential parts of the masonry. In some instances, it is difficult to procure a solid foundation, and the usual methods of piling, grating, and planking, are resorted to. (See Chap. III.)

155. But the protection of the commerce of Great Britain required that light-houses should be erected on isolated rocks of the ocean; noble works, which no man can regard with indifference, rearing their heads amidst the tumultuous waves, while the dwellers within trim their lamps in safety, to guide their endangered fellow-creatures through the perils of the storm. (See

plate XXIII.) To raise a permanent light-house on a rock covered by the sea at high-water, was first attempted at the Eddystone; two were erected chiefly of timber and destroyed, the one by a storm, and the other by fire. Mr. Smeaton designed another to be executed in stone, it was erected, and still remains a proud monument of the skill of that celebrated engineer.

The Eddystone Light-house.

156. Mr. Smeaton's first journey to Plymouth, upon the business of the Eddystone light-house, as will be seen from his excellent narrative of the work, was in the month of March, 1756; and, on the 5th of April, the following month, he landed, for the first time, on Eddystone-rock. In the course of the ensuing winter, and following spring, arrangements were made for proceeding with the building operations. A large stock of materials had been provided, and various experiments were made by Mr. Smeaton with lime-stone from different parts of the coast, which enabled him to conclude, that a mixture of lime from Aberthaw, in the Bristol channel, and puzzolano earth from Italy, was the proper mortar for this building. (See *art.* 62.) A stock of oak trenails was provided for fixing the newly-laid stones to the rock, or to the course below, which, with the system of dove-tailing and joggling, (see *plate* XXIII, *fig.* 3,) prevented them from being carried away before the mortar took bond, or while the respective courses were in an unfinished state. Things being thus in preparation for the second year's operations, the attending-vessel was moored in her place, near the rock, and the foundation-stone of the building was laid on the 12th of June, 1757; and, by much perseverance, the ninth course, or third entire course above the top of the rock, was completed by the last day of September, with which the season's work was successfully closed. Owing to several disappointments, the commencement of the work at the rock did not take place till the 2d day of July, 1758, when part of the 10th course was landed; and, by the 8th of August, the 14th course, or solid part of the building, was completed, which brought the work to the entrance-door, or to the height of 12 feet above the top of the rock; and, by the latter end of September, the 24th course, forming the top of the staircase and floor of the first apartment, or store-room, was laid. The work being continued till the beginning of the month of October, the outward circle of the 29th course, or the arched roof of the store-room, was laid. It was not till the latter end of March following, that a favourable opportunity was afforded to Mr. Jessop, the assistant-engineer, for landing at the rock, when he found every thing nearly in the same state in which it had been left in the month of October, excepting one stone of the upper or unfinished course, which the workmen were in the act of laying, when they were obliged hastily to leave the rock. This stone had been carried away from its having, perhaps, been left too near the outer verge of the building. But it deserves notice, that the wooden centering, for carrying the arch or dome over the store-room, was found in its place, after all the gales of winter, together with a set of wooden triangles, which had been left on the top of

the building, and were found, on landing in the spring, to be in good condition, together with a stone which was ready to be laid, and was still found suspended by the tackle. By the middle of the month of June, 1759, in the fourth and last year of the work, the whole of the stones were hewn early in the season, and were ready to ship from the work-yard to the rock. The work commenced this season on the 5th of July, and by the 17th of August following, the balcony and upper course of the cornice was laid, which completed the masonry of the Eddystone light-house.

The exterior parts of the building which are exposed to the action of the sea are of granite, the interior of Portland stone. *Fig.* 5, shows the continued chain which is inserted to assist the tendency to spread from the thrust of the floors; and *fig.* 4, the cramps and dowels in the other courses.

The Bell Rock Light-house.

157. The Bell Rock light-house is nearly of the same form as the Eddystone, with some improvements in the mode of constructing the upper parts of the work. *Fig.* 1, *plate* XXIII, is an elevation; and *fig.* 2, a section of the Bell Rock light-house. The Bell Rock itself is a sunken reef of sand-stone, the highest part only being uncovered at ordinary ebb-tides. The nearest land to the Bell Rock is the town of Arbroath, from which it lies in a south-eastern direction, about 11 miles distant. The dimensions of the part of the rock which become dry in spring-tides are, about 400 feet in length, and 250 in breadth; at flood-tides, the whole rock is from 10 to 12 feet under water, and it presents a very rugged surface. In regard to the depth of the sea near the Bell Rock, it appears that, at the distance of about 100 yards, in a low state of the tide, the water varies from two to three fathoms in depth. Between the rock and the opposite shore of Fife the greatest depth is 23 fathoms; but on the south-east, or seaward side, it increases suddenly to 23 fathoms. The observations made upon the currents at the rock are curious. Although a mere spot on the surface of the ocean, it produces all the remarkable phenomena of in-shore and off-shore tides, which are noticeable on the projecting coasts of the mainland, or among the Scottish islands.

Mr. Stevenson first landed on the rock in the summer of 1800; and became satisfied of the practicability of erecting a stone light-house on this fatal reef, upon principles similar to those employed by Smeaton in the construction of the Eddystone one, and reported to that effect to the Commissioners of Northern Light-houses, who also consulted Mr. Rennie on the subject; and the work was commenced in 1807.

From the insulated and distant situation of this rock, the first object was to moor the tender for the exhibition of a temporary light, and for the convenient residence of the artificers. A vessel was also provided for carrying workmen between the shore and the rock. Quarries were opened near Aberdeen for supplying granite for the outward courses of the building, and at Kingoodie, near Dundee, for supplying sand-stone for the interior. The principal establish-

ment on shore was fixed at Arbroath, where a large enclosure was procured for the preparation of the stones, connected with barracks for the accommodation of the artificers. By strenuous and unremitting exertions the beacon-house was erected, and the foundations of the building prepared by the middle of the month of July, in the second season of the work. The foundation had the appearance of a great circular platform of compact red sand-stone, measuring 42 feet in diameter, surrounded by an irregular margin of rock, rising from 18 inches to 5 feet. In the work-yard at Arbroath, where the materials were prepared, the first and second courses of the light-house now lay ready for being shipped for the rock. Each stone was accurately marked, so that its relative position in the building on the rock could at once be recognised. The stones were cut of a dove-tail form, on a plan similar to those of the Eddystone light-house. The foundation-stone at the Bell Rock was laid by Mr. Stevenson with masonic ceremony, on the 10th of July, 1808; and, by the latter end of September, the works were brought to a conclusion for the season. The building, being now on a level with the highest part of the margin of the foundation-pit, or about 5 feet 6 inches above the lower bed of the foundation-stone, is computed at 388 tons of stone, consisting of 400 blocks, connected by 738 oaken trenails, and 1215 pairs of oaken wedges. The number of hours of low-water work upon the rock this season was 265, of which number only 80 were employed in building.

In the spring of the year 1809, the operations re-commenced. Every thing was found to have withstood the effects of the winter's storms, all the courses which had been laid, and the beacon itself, now in the third year from its erection, remaining quite entire; and with that season was completed the 24th course, reckoning above the first entire one, and the 26th above the rock. This finished the solid part of the building, and terminated the height of the outward casing of granite, which is 31 feet 6 inches above the rock, or site of the foundation-stone, and about 17 feet above high-water, at spring-tides. The first circumstance attended to in commencing the building operations of 1810 was to fix upon the proper position of the entrance-door of the light-house. In this Mr. Stevenson was assisted by carefully observing the range of the sea upon the solid part of the building, and by tracing the growth of fuci and confervæ on the walls. The heaviest sea being in this manner determined to be from the north-east, the door was consequently laid off towards the south-west. This and other preliminary steps having been taken, the first cargo of stones was brought to the rock about the middle of May; and, from the very complete and systematic arrangement of the works, the building operations were brought to a close during the month of August, without any material obstacle having been experienced. This greatly increased facility in building, was ascribed partly to the experience acquired by practice in former seasons, in landing and raising the materials. *Plate* XXIII, contains an elevation and section of the light-house, to which we refer our readers. Having already noticed the manner of attaching the lower courses of the stones, which was similar to that resorted to at the Eddystone, we shall now advert to the plan followed for the upper or habitable part. At the stone staircase, leading from the door to the first floor, the

wall is of the medium thickness of about 7 feet, and gradually diminishes upwards, till, under the cornice of the building, it is only 18 inches. The stones of the walls of the several apartments are connected at the ends with dove-tail joints instead of square joggles, as in the solid and in the stair-case; while the bed-joints are fairly imbedded in each other by means of a girth raised upon the one stone, and sunk into the other. The floors are also constructed in a manner which adds much to the bond or union of the fabric. Instead of being arched, which would give a tendency or pressure outwards on the walls, the floors are formed of long stones, radiating from the centre of the respective apartments, and at the same time forming a course of the outward walls of the building. These floor-stones are also joggled sideways, and, upon the whole, form a complete girth at each story. In this manner, the pressure of the floors is rendered perpendicular, while the side-joggles resemble the groove and feather in carpentry. In the strangers'-room, or library, the roof takes an arched form, but the curve is cut only upon the interior ends of the stones of the cornice, the several courses of which it is composed being all laid upon level beds.

On the 2d of February, 1811, it was lighted for the first time. The light is clear and powerful, and may be seen, when the sky is clear, very distinctly at eight leagues distance. The light is alternately red and white.

"Far in the bosom of the deep,
O'er the wide shelves my watch I keep—
A ruddy gem of changeful light,
Bound on the dusky brow of night;
The seaman scuds, my lustre hails,
And seems to strike his timorous sails."—Sir W. Scott.

CHAPTER VIII.

ORNAMENTAL MASONRY.

158. Ornamental Masonry includes the construction of columns and the parts connected with them, stairs, chimney-pieces, and monuments.

159. Of COLUMNS.—These comprise, generally, a conoidal shaft, with a diminution towards their upper diameter, which is, generally, about one-sixth less than the lower diameter. The proportions of columns, among the Egyptians, varied but little; the columns of this people, in their large temples, were only about four and a half diameters in height. Those of Greece vary considerably; the Doric from $4\frac{2}{3}$ to $6\frac{1}{2}$ diameters; those of the *Parthenon*, at Athens, are little more than five. In the best Roman examples, the proportion of the Doric was increased to seven diameters. The columns of *all* the Grecian remains are fluted. The Doric

shafts have for their flutes very flat segments of circles, finished to an arris: but sometimes flutings of the semi-elliptical shape were adopted. The genius of an architect is generally displayed in the application of columns. The Greeks surrounded their public walks with them; and in their porticos carried this kind of splendour to its highest pitch. To construct a temple, in the Greek manner, required the greatest taste and judgment, combined with a perfect knowledge of architecture. The Parthenon, at Athens, was, without exception, the most elaborate piece of masonry in the world.

The comparatively perfect state in which the monuments of Greece remain, is a proof of the perfection with which they were constructed. The famous Temple of Minerva would have been entire to this day, if it had not been destroyed by a bomb. The *Propylea*, which was used as a magazine for powder, was struck by lightning and blown up. The Temple of Theseus, having escaped accidental destruction, is almost as entire as when first erected. The little choragic monument of Thrasybulus, as well as that of Lysicrates, are also entire. These instances should impress on modern architects the utility of employing large blocks, of uniting them with the greatest accuracy, and giving the highest degree of finish to the whole.

160. The joining of columns in free-stone, has been found more difficult than in marble; and the practice used by the French masons, to avoid the failure of the two arrises of the joint, might be used with success for constructing columns of some of our softer kinds of free-stone. It consists in taking away the edge of the joints, by which means a groove is formed at every one throughout the whole column. This method is employed only in plain shafts. It appears to have been occasionally used by the antients, though for a different purpose; *viz.* to admit the shaft to be adorned with flowers, and other insignia, on the occasion of their shows and games. In the French capital, they affix rows of lamps on their columns, making use of these grooves to adjust them regularly, which produces a very good effect.

161. The shafts of columns, in large works, intended to be adorned by flutes, are sometimes put up plain, and the flutings chiselled out afterwards. The Greeks commonly formed the two extreme ends of the fluting previously, as may be seen in the remaining columns of the Temple of Apollo, in the Island of Delos; a practice admitting great accuracy and neatness. The finishing the detail of both sculpture and masonry on the building itself, was a very common practice among the antients: they raised their columns first in rough blocks, on them they placed the architraves and friezes, and surmounted the whole by the cornice; finishing down only such parts as could not be got at in the building; hence, perhaps, in some measure, arose that striking proportion of parts, together with the beautiful curvature and finish given to all the profiles in Grecian buildings. In modern works, a greater command of the mechanical powers, and more accurate methods of arranging the parts of large works, causes the more scientific practice of executing them in parts to be preferred.

When a plumb-rule is applied to try if the axis of the column be exactly vertical, the rule should be so held that its plane surface, if produced, would pass every where through the axis.

162. With regard to the practice of the ancients, in diminishing the shafts of their columns, nothing can be learned from the writings of Vitruvius, since his text is so very obscurely expressed as not to be understood. It has been always supposed by modern writers on architecture, that the contour of the columns was that of a convex curve, called by Vitruvius the entasis. Some writers have supposed that the greatest diameter of the shaft was not at the extremities, but at some intermediate section of its height; and the practice of modern architects of the last century was to make the shaft cylindrical to one-third part of the height, and thence to lessen the diameter continually, so that the sides might form a convex curve.

163. Sir William Chambers recommends the trammel, which Nicomedes used for the description of his first conchoid, as being best adapted for this purpose, as this instrument gives at one sweep both the entasis and diminution. We must, however, observe, that the instrument of Nicomedes is not only cumbersome, but inconvenient to use, on account of its requiring so much room, in order to place it and to describe the curve. He moreover says, that it is universally allowed to be the most perfect practice hitherto discovered; and that the columns of the Pantheon, accounted the most beautiful among the antiques, are traced in this manner, as appears by the exact measures of one of them to be found in Desgotez's Antiquities of Rome.

164. How columns could be executed with such exactness, or how the dimensions, after standing so many hundred years, could be taken with such accuracy as to ascertain that the curve-line of their sides was that of the conchoid, we are at a loss to know, since the curvature of all curves, at the vertex, is very nearly equal when the radius of curvature is equal; so that many curves of different properties, as the circle, the ellipse of any given eccentricity, the parabola, the conchoid, &c., may be all drawn through three given points, without its being possible to discover any deviation. And thus it will appear, that the dimensions given of the shafts of the columns of the Pantheon prove nothing; so that, in point of fact, when the curvature differs but little from a right line, the entasis formed by any known geometrical curve must be equally agreeable to the eye, whether we use a portion of one curve, or a portion of another. It will, however, be most convenient to employ such a curve as can be the most easily described, and, at the same time, will require the least space to perform the operation.

165. It is singular that Stewart, the celebrated author of the Antiquities of Athens, has not favoured us with the measures of the contours of the columns, taken upon sections through the axes of the shafts of the columns of any Grecian edifice.

Mr. Reveley, an ingenious traveller, in his Defence of Grecian Architecture, in answer to the attacks of Sir William Chambers, says, that the contours of the columns of Grecian temples were executed in the most graceful sweeping lines, but does not confirm this assertion by any example. "The entasis of columns has not till lately formed a part of the critical study and observation of the student of Grecian architecture, and had escaped even the exact and minute attention of

Stewart and Revett; yet, of its importance, no one will doubt, who considers but for a moment how much of beauty depends upon the nicely-executed contour of the shaft of the column."

The entasis, in every instance, (here given,*) are produced from the bottom of the column, but none have the entasis perceptible to the eye, and scarcely to the rule, so slight is it; from which we cannot but infer, that it never was the intention of Grecian architects to produce any other effect to the eye of the beholder than that of a straight line; nor are we aware that there is an example now remaining, but the columns of the Pseudodipteral temple at Pæstum.

These conclusions are corroborated by the observations of Mr. Wilkins, in his excellent translation of Vitruvius, where he says, if the fillet between the flutings of the Ionic columns be the measure of the entasis of Vitruvius, the deviation from a straight line will be scarcely perceptible in the outline of a column.

166. These facts seem at variance with the ideas of modern architects and authors, who assert, that columns which have their shafts in the figure of the frustum of a cone appear concave to the eye. This concavity, however, is a delusion of the senses, generated by constantly seeing the shafts of columns diminished in a convex curve. We will venture to affirm, that had they been accustomed always to view conic or cylindric shafts instead of conoidal shafts, the notion of their being concave would never have been so generally impressed.

167. Some columns are fluted round the shaft to the number of twenty-four, with as many fillets, one between every two flutes, as in the Ionic, Corinthian, and Composite orders; and some columns are fluted without fillets, as in the Doric order, the profiles of the flutes being generally a segment of a circle less than a semi-circle. Semi-circular flutings are generally used in Roman architecture, the proportion between a fillet and a flute being as one to three, or as one to four; and, in the columns of Grecian architecture, the profile of the flutes in the Ionic and Corinthian orders is a semi-ellipse surbased, the proportion of a fillet and a flute is from one to five to from one to seven.

168. OF PILASTERS. — Pilasters are rectangular trunks of stone, employed in Roman architecture in place of columns, and may belong to any of the five orders.

In Roman architecture, when detached columns are employed, pilasters are always ranged behind the columns; and if such columns are placed within a recess, besides the pilasters behind the columns, a pilaster is attached to each of the flank-walls, so as to range with the columns and to support the ends of the entablature over them; in this case, a quarter pilaster must be placed in each interior angle of the recess, so as to range with the pilasters behind the columns

* See Stewart's Antiquities of Athens, published by Priestly and Weale, Volume IV., parts Sixth and Seventh, by Mr. William Jenkins, Jun. Plate 4, belonging to the same parts, exhibits the sections of the shafts through the axis of the Portico and North wing of the Propylea, the temple of Theseus, the temple of Minerva, and the Choragic monument at Athens; and Plate 5 exhibits the sections through the axes of the shafts of the columns of the north and east porticos of the triple temple, called the Erectheum, at Athens; and those of the portico and pronaos of the temple of Jupiter Panhellenius, at Ægina.

and with the two pilasters in the range of the columns, as also to support the extremities of the entablature over the pilasters behind the columns and the extremities of the two entablatures over the pilasters upon the flanks of the recess; but, if a range of insulated columns are placed partly within a recess and partly without, the two extreme pilasters in the range of the columns must then exhibit two complete faces, one parallel to the front of the building, and one parallel to each of the flank-walls.

169. In Roman architecture, pilasters arranged behind ought to diminish, and to have an entasis in an equal degree to those of the columns, so that the bases and capitals may not only range in a horizontal line, but also that the capitals may preserve the same proportion in their outline as those of the columns. Ancient examples, in which this is particularly observed, may be seen in the Temple of Mars the Avenger, in the Frontispiece of Nero, in the Portico of Septimus Severus, and in the Arch of Constantine at Rome; but, if they are arranged upon a wall, without columns, their faces and returning edges ought to be rectangular parallelograms.

170. Engaged pilasters are employed in Churches, Galleries, Halls, &c., in order to save room; for they seldom project beyond the naked of the walls more than one-quarter of their breadth, and do not occupy near so much space as engaged columns. They are sometimes employed in exterior decorations instead of columns, and sometimes alone, on account of their being less expensive, as at the Duke of Queensberry's house in Burlington-Gardens, General Wade's house in the same place, and in many other buildings in London. Examples where they accompany columns, being placed behind them, may be seen in the portico of the Pantheon at Rome, and in the portico of St. Martin-in-the-Fields; and examples in which they range with, and flank the columns, may be seen in the portico of Septimus Severus at Rome, and in the church of St. Lawrence Jewry, London. The projection of pilasters behind columns need not be so great as when they are alone.

171. The trunks of pilasters are sometimes adorned with flutings, in the same manner as the columns of the same order. The profile of the flutes ought never to exceed a semi-circle, and in order that they may be of the same dimensions as in columns of the same magnitude and specie, the breadth of the front ought to contain seven flutes, making each interval equal to a third or a fourth part of the breadth of each flute; and when the pilaster is within the reach of accidents, and thereby liable to be broken, the angle must be taken away by an astragal, leaving a fillet between the moulding and the adjacent flute. The flutes, as in columns, may be filled with cablings to one-third of their height, and the returning sides of pilasters ought to be of such breadth as to terminate upon the naked of the wall in a fillet.

172. The capitals of Tuscan and Doric pilasters are profiled in the same manner as those of the respective columns; but, in the capitals of the other orders, there is some trifling difference to be observed. In the antique Ionic capital, the extraordinary projection of the ovolo makes it necessary either to bend it inwardly, at the extremities, that it may pass behind the volutes, or, instead of keeping the volutes flat on the front, as they commonly are in the antique, to

twist them till they give room for the passage of the ovolo. The same difficulty exists with regard to the passage of the ovolo behind the angular volutes. However, in order that the faces of the volutes may be in a vertical plane, and to afford room for the ovolo behind them, the plane which contains their projecting lines, must project in a much greater degree before the face of the pilaster than those which belong to columns of the same kind. This idea has been recommended by Scamozzi, and has been practised by Inigo Jones, in the Banqueting-house at Whitehall. What has been said in respect of the Ionic capital, will, in a certain degree, apply to the capitals of the Composite and Corinthian orders.

173. The employment of half, or other parts of pilasters, of which their vertical planes intersect in *re-entrant* and *sailent* angles, should be avoided as much as possible, since it generally occasions irregularities in the entablatures, and sometimes also in the capitals. Particular care must be taken never to introduce more than one of these breaks in the same place, for more can never be necessary.

174. OF ANTÆ.—Antæ are a species of pilasters employed in Grecian architecture, either behind each extreme column of a range of columns, or in the range of the columns themselves, when there are only two intermediate ones; and, though there are no instances in which antæ are placed behind intermediate columns in a range, yet the monument of Philopapus affords an example in which pilasters are used in Greek architecture, in a range projecting from, and attached to, the wall, half the breadth of their fronts. As the word *antæ* signifies before, the Greeks called all those square pillars which stood before, and were attached to, the ends of walls, by the name of antæ. We cannot, therefore, give this name to a series of rectangular pillars attached to the face of a wall; besides, the bases and capitals of antæ differ entirely in their compositions from those of the columns which they accompany; but, in pilasters, they were always of the same specific order; and in the example of the monument of Philopapus, just alluded to, the capitals and bases are of the genuine Grecian Corinthian order: so that pilasters, though used profusely in Roman architecture, are not entirely confined to it; for though they do not abound, are yet to be found in the magnificent ruins of Grecian edifices.

175. This much we have said, as some writers on architecture confound antæ with pilasters; and no author, that we are aware of, has pointed out their specific applications, though they inform us, generally, that the capitals of antæ differ in their form and proportion from the capitals of the columns with which they are associated.

176. Antæ are not always diminished, and when they are, the diminution is very small, and not generally equal to that of the columns with which they are placed. In Greek architecture, as the architrave generally projected some considerable distance over the tops of the shafts of the columns, and as the flanks of the antæ never projected beyond the vertical face of the architrave adjacent to the capitals of the columns, these limits allowed very great latitude for the breadth of the upper extremities of the antæ: and thus we find that such liberties were taken by Grecian architects, as is confirmed by the remains of ancient edifices; for the breadths

of the tops of the pillars of the antæ, and the upper diameters of the shafts of their respective columns, did not always bear the same proportion to one another, but, in different edifices, had most frequently different proportions.

177. ON PARASTATÆ.—Parastatæ are square isolated pillars, with bases, capitals, and entablatures, according to any of the Greek orders of architecture, or to any fanciful composition in the manner of an order; the bases and capitals may be similar to those of antæ, and the entablature may be that of any of the five orders. The monument of Trasyllus, at Athens, affords an example where one parastatæ is employed between two *antæ*, in the same manner as two columns are placed between the antæ of a temple in antes.

178. ON ATTICS.—An attic is a kind of dwarf order, with pilasters instead of columns. Attics are sometimes employed instead of a second order, to crown the first by an ornamental piece of masonry. The height of an attic should never exceed one-third of the height of the order on which it is placed, nor ever be less than one-quarter. The base, die, and cornice of which they are composed, may have the same proportions to each other as the corresponding parts of pedestals to which they resemble. Sometimes these attics are continued without any breaks; and, at other times, they project and form pilasters which may be said to be stunted, as they are not so elongated as those which belong to a regular order, but at the same time are generally higher than pedestals. Pilasters, thus formed, are called attic-pilasters, and the pilasters and entablature are together called the attic order.

179. The breadths of these pilasters ought to be equal to the upper diameter of the columns or pilasters under them, and their projectures may be any distance between one-quarter and one-fifth part of the breadth of their fronts. The fronts are most frequently plain; they are sometimes, however, adorned with panels which are surrounded with mouldings.

180. PARAPETS.—Parapets are very ornamental to the upper part of an edifice. They were used by the Greeks and Romans, and are composed of three parts; viz. the *plinth*, which is the blocking-course to the cornice; the *base*, which is the part immediately above the plinth; and the *die*, surmounted by a cornice, which projects in its moulding, sufficiently to carry off the rain-water from the die and plinth. Architects have devised the parapet with reference to the roof of the building which it is intended to obscure.

181. ASHLARING.—Ashlaring is a term used by masons to designate the plain stone-work of the front of a building, in which all that is regarded is getting the stone to a smooth face, called its *plain work*. The courses should not be too high, and the joints should be crossed regularly, which will improve its appearance, and add to its solidity.

182. CILLS.—These belong to the apertures of the doors and windows, at the bottom of which they are fixed; their thickness varies, but is commonly about one inch and a half; they are also fluted on their under edges, and sunk on their upper sides, projecting about two inches, in general, beyond the ashlaring.

183. CORNICE.—This forms the crown to the ashlaring, at the summit of a building; it is frequently the part which is marked particularly by the architect, to designate the particular order of his work; hence *Doric, Ionic,* and *Corinthian,* cornices are employed, when, perhaps, no column of either is used in the work; so that the cornice alone designates the particular style of the building. In working the cornice, the top or upper side should be splayed away towards its front edge, that it may more readily carry off the water. At the joint of each of the stones of the cornice, throughout the whole length of the building, that part of each stone which comes nearest at the joints, should be left projecting upwards a small way; a process by workmen called *saddling* the joints; this is done to keep the rain-water from entering them, and washing out the cement. These joints should be chased or indented, and such chases filled with lead, and even when dowels of iron are employed, they should be fixed by melted lead, or, which is more preferable, filled with Roman cement.

184. RUSTICATING, in architecture and masonry, consists in forming horizontal sinkings, or grooves, in the stone ashlaring of an elevation, intersected by vertical or cross ones; perhaps invented to break the plainness of the wall, and denote more obviously the bond of the stones. It is often formed by splaying away the edge of the stone only; in this style, the groove forms the elbow of a geometrical square. Many architects omit the vertical grooves in rustics, so that their walls present an uniform series of horizontal sinkings. There are many examples, both antient and modern, of each kind.

185. BASEMENTS.—Instead of employing several orders, one above the other, in a composition, the wall of the ground-floor is sometimes made in the form of a continued base, called a *Basement,* on which the order that decorates the principal story is placed. The proportion of these basements is not fixed. It depends upon various circumstances; but chiefly upon the nature of the apartments composing the ground-floor, without having any relative proportion to the order above. It will not, however, on any occasion, be advisable to make the basement higher than the order it has to support, nor should it be lower than half the order, if it has to contain apartments.

186. The usual manner of decorating basements is with rustics of different kinds. The heights of the rustics, including the joints, should never be less, nor much more, than one module of the superior order; and the figure of a full rustic may be that of a triple square. The joints between them may either be rectangular, with one face parallel to the plane of the rustic, and the two receding sides perpendicular to the plane of the face of the said rustic; or the joints of the rustics may exhibit two planes of equal breadth, forming with each other a right angle. Those which have three sides, ought not to be wider than one-eighth part of the height of the rustic nor narrower than one-tenth part, and the depth about one-half of their breadth. Those rustics which exhibit two sides are called *champhered rustics,* and those which exhibit three sides are called *square rustics.* The whole recess is called a joint.

187. It is a very general practice in France, to form the joints of rustics in a variety of different figures; and very frequently to execute them with horizontal joints only.

188. Rustics with horizontal joints are very frequently practised in Great Britain, and throughout the British dominions. The ancient Romans formed their rustics both with horizontal and perpendicular joints, and in this they have been followed by the modern Italian architects.

189 Rusticated Basements which are high are sometimes finished with a cornice, as in the Strand-front of Somerset-Place; but the usual practice is only to crown it with a plat-band, of which the height should not exceed that of the rustics, including the joint, nor lower than a rustic, exclusive of the joint. The plinth, at the foot of the basement, must be at least equal to the height of the plat-band.

190. Whenever there are arches in the basement, the plat-band which supplies the impost must be of the same height as one of the rustics, exclusive of the joint; and where a cornice is introduced to finish the basement, a regular moulded base to the same must be introduced. To the height of the cornice may be given one-eighteenth part of the whole basement, and to that of the base about twice as much; which, being divided into six equal parts, the lower five parts may form the plinth, and the upper sixth part the moulded cornice.

191. ARCHITRAVES adorn the apertures of a building, projecting somewhat from the face of the ashlaring; they have their faces sunk with mouldings, and also their outside edges. When they surround the curve formed in the face of an arch by the intrados, they are called *archivolts*. Archivolts give beauty to the exterior of a building, and the best examples of them are to be found among the Roman buildings, since it is doubtful whether ever the Greeks were acquainted with the use of the arch.

192. ORNAMENTS OF APERTURES. — The ornaments of apertures are of several varieties: the most simple method of adorning doors and windows is with an architrave, surrounding the two vertical sides and the head. When the aperture is remarkably high, with respect to the width, it becomes necessary to enlarge the breadth of the ornaments on the sides, either with pilasters or consoles, and sometimes with both, in order to give the whole composition an agreeable proportion.

193. When an edifice consists of several floors, the principal story may have its windows decorated with a frieze and cornice, surmounting an architrave bordering the aperture, and sometimes, instead of the architrave, frieze, and cornice, the simple architrave is surrounded with columns on the flanks, and a regular entablature surmounting the columns; but the windows of the other stories ought either to have no ornaments, or a plain architrave bordering the aperture only. When the ground-story is rusticated, the rustics ought not to return upon the reveals of the windows, but either upon the flanks of an architrave or pilaster, or upon a plain margin surrounding the aperture. Sometimes this margin is made so broad as to admit of an architrave.

194. In the application of architraves to doors and windows, the breadth of the architrave

should never be less than one-sixth part of the breadth of the aperture; but in some respects considerably more, when other dressings are introduced on the flanks, as in the entrance-door ways of the new church of St. Pancras.

195. In the most admired works of architecture, we find the same object generally continued throughout the same level; but the dressings of windows in any two stories may differ from each other. Sometimes, however, when the front of the building is broken into three or more plane faces, the centre, and sometimes the extreme breaks, may be adorned with Venetian, and sometimes with Scamozzian, windows.

196. It has been supposed that the practice of diminishing the upper part of the apertures of doors and windows was derived by the Greeks from Egypt; but, in reality, the apertures of Egyptian monuments are found to be of equal dimensions at the top as at the bottom, though the ornaments round them (which may have misled the eye) have a considerable diminution.

197. PEDIMENTS.—A Pediment is an ornament formed with a horizontal cornice, and two equally-inclined straight cornices rising from the extremities of the horizontal cornice, and meeting each other in a vertical plane bisecting the length of the horizontal cornice, so that the three cornices may comprise a triangular space called the tympanum. Sometimes, instead of two equally-inclined cornices, one circular cornice is used, which, with the horizontal cornice, forms a tympanum in the figure of a segment of a circle.

198. Pediments, with straight inclined cornices, are called triangular pediments, and those which have a circular cornice are called circular pediments. Circular pediments are never so proper as triangular pediments; they are sometimes used, however, over the apertures of doors and windows, alternately with triangular pediments, in order to give variety to the general façade. Circular pediments ought never to be employed upon the gable ends of buildings, or to surmount the cornice of an order, as they are neither so elegant, nor so useful in discharging the rain-water from the upper surface.

199. Triangular pediments only were used among the Greeks; but the Romans employed not only triangular but circular pediments also over the apertures of doors and windows; but never upon the gable ends of buildings, as is done by the modern Italians.

200. Some writers object to pediments used in interior decorations, because, when the whole is covered (they say) there can be no occasion for a covering to shelter each particular part. Beauty and fitness, however, have frequently but little connection with each other, and in architecture they are sometimes incompatible; and there are many things, which, though beautiful in the highest degree, yet carry with them, in their application, an evident absurdity. One instance which is in the Corinthian capital: a form composed of a slight basket, surrounded with leaves and flowers; can any thing be more unfit to support an entablature, consisting of a heavy mass of materials? yet the Corinthian capital has been approved of and admired for some thousand years, and will probably still continue to be approved of for ages to come.

201. There are some improprieties in the use of pediments, which ought never to be admitted in exterior decorations: such as the arched head of a door or window to break the horizontal cornice; as this application at once destroys the tie which connects the inclined cornices: nor should any interval be left between the inclined cornices, since the pediment represents the end of a roof, for such a mutilation would represent an imperfect and unprotected house.

202. Vitruvius observes, that the Greeks never employed modillions or dentils in their pediments, both of them representing the parts in the construction of a roof which only appear in the flanks of the building. However, be this as it will, there are very few Grecian buildings in which dentils and modillions are not employed in the horizontal cornices of pediments, as well as in flanks of the building, though there are scarcely any instances in which modillions or dentils can be found in the inclined cornices of pediments, as was the practice of Roman architects.

203. It is to be observed, that the uppermost mouldings in the profiles which form the extremities of the horizontal cornice, are not extended along the horizontal cornice, being only applied as a covering to the pediment.

204. The proportions of pediments depend upon their size; for the same proportions which have a good effect in a wide aperture, will not succeed in one which is narrower. When the base of the pediment is short, but placed at a great height, its height must be increased; and when the base of the pediment is very long, compared to its height above the horizon, the height of the pediment must be diminished; for, when the length of the level cornice is small, as the inclined cornice is proportioned to the height of the order, they would leave no room between them and the horizontal cornice, and, consequently, would not have any tympanum. In short, the height of the pediment must be regulated by the height of the aperture, or by the height of the order, accordingly as it accompanies an aperture or order.

205. The face of the tympanum is always placed in the same plane which contains the frieze of the entablature, and is frequently adorned with sculpture; and the pediment is often surmounted with square blocks of stone, called *acroteries*, which, according to Vitruvius, are equal in height to the tympanum.

206. BLOCKING COURSE.—This is a course of stone, extending along the top of the cornice upon which it is fixed; it is commonly, in its height, equal to the projection of the cornice, and is of great utility in giving support to the latter by its weight, and, besides, it adds grace and dignity to the entire composition of the façade. At the same time, it admits of gutters behind it to convey the superfluous water from the covering of the building. The joints should always cross those of the cornice, and should be plugged with lead, or cramped on their upper edges with iron. The Romans often dove-tailed such courses of stone.

207. BALUSTRADE.—A Balustrade is a row of small pillars supporting a continued string, in the same manner as a series of columns of any order support their entablature; the pillars are called *balusters*, and the string is called the *rail*. The use of the balustrade is to perform the office of a parapet, by a more light and aerial construction.

208. Balusters are sometimes of real use in a building, and at other times they are merely ornamental. Such as are intended for use, as when they are employed on steps, or stairs, or before windows, or to enclose a terrace, or other elevated place of resort, must always be nearly of the same height, which ought to be between three feet and three feet six inches; so that a person of ordinary size may lean over them with ease, and without being in danger of falling. But those which are principally designed for ornament, as when they finish a building, or even for use and ornament, as when they enclose a passage over a large bridge, ought to be proportioned to the architecture they accompany, and their height, without the plinth, ought never to exceed four-fifths, nor be less than two-thirds, of the height of the entablature, on which they are sometimes placed. The height of the plinth must be sufficient to leave the whole balustrade exposed to view when seen from a proper point.

209. A good proportion for a balustrade with single-bellied balusters is to divide the given height into thirteen equal parts, to make the height of the base three of these parts, the balusters eight, and the height of the rail equal to the remaining two; or, when the balustrade stands very high, the whole height may be divided into fourteen equal parts, giving four for the height of the base, eight for the balusters, and two for the rail.

210. The double-bellied balusters being the lightest, are the most proper to accompany windows, or other compositions, in which the parts are small and the profiles delicate. The bases of these balusters may have the same profile as that of the single-bellied ones; but they must not be quite so large. In these, the height must be divided into fourteen equal parts, of which the height of the base may contain three, the baluster nine, and the rail two. The side of the square plinth is generally equal to the diameter of the greatest circle of belly. In balustrades, the distance between two balusters should not exceed the half, nor be less than one-third, of the diameter of the baluster or the side of the square plinth.

211. The pedestals which support the rail should be at such a distance from each other as to contain eight or nine balusters, besides the two half-ones engaged on the flanks of the pedestals. But the disposition of the pedestals depend on the situation of the piers, pilasters, or columns, in the front, it being always deemed necessary to place a pedestal directly over the middle of each of these. By attending to this circumstance, it frequently happens that the intervals are sufficient to contain sixteen or even eighteen balusters: in this case, the pedestals may be flanked with half-dies, and each range may be divided into two, or which is better, into three intervals, by placing one or two dies in the range, the dies being, in all cases, flanked with two half-balusters. The breadth of these dies being from two-thirds to three-quarters of the breadth of the dies of the pedestals. As these intermediate dies are introduced to strengthen the rail and to break the long ranges, the rail and the base should be continued in a straight line between the dies of the pedestals, otherwise they would predominate and destroy the appearance of those placed over the central lines of the piers, or over the central lines of the columns.

212. When an order is surmounted by a balustrade, the breadth of the dies over the columns or pilasters should never exceed, nor even be much narrower, than the superior diameter of the shaft of the column, or the superior breadth of the front of the pilasters; and when there are neither columns nor pilasters in the composition, the die should never be much broader than its height, and very seldom narrower.

213. The use of balusters was unknown among the ancients: there is no trace of them among any of their works; they were introduced into architecture by the modern architects of Italy, in whose productions the most ancient balusters are to be found. The most elegant forms are those exhibited in the works of Palladio.

214. FASCIA is a plain course of stone, generally about one foot in height, projecting about an inch before the face of the ashlaring, or in a line with the plinth of the building: it is fluted or *throated* on its under edge, to prevent the water from running over the ashlaring; its upper edge is sloped downwards for the same purpose. It is commonly inserted above the windows of the ground-stories; *viz.* between them and those of the principal story.

215. A PLINTH, in masonry, is the first stone or rows of stones inserted above the ground: it is in one or more pieces, according to its situation, projecting beyond the walls above it about an inch, with its projecting edge sloped downwards, or moulded, to carry off the water that may fall on it.

216. IMPOSTS.—These are projections of stone, under each springing of an arch, with their front faces generally moulded; when left plain, they are prepared in a similar manner to the facias. They form the spring-stones to the arches in the apertures of a building.

217. CHIMNEY SHAFTS.—A Chimney shaft is a turret projecting upwards above the roof of a house, in order to conduct the funnels, and to discharge the smoke above the top of the building.

218. The shafts of chimney-funnels should be regularly disposed on the roofs of buildings, and all of them be made of the same height: moreover, when they stand in the same range, they ought to be of the same breadth. The most handsome are those constructed of a rectangular figure, and finished with a light cornice, surmounted by a blocking-course. Scamozzi recommends obelisks and vases; Serlio has given designs for decorating the tops of funnels, which are in the form of towers; and Sir John Vanbrugh frequently converted his into castles, as may be seen at Blenheim, Castle Howard, and others of his numerous stately works. Neither the Italians, nor the Englishman above cited, have been very successful in their designs; but, upon the same ideas, good ones might be composed, and may be made to terminate a structure with elegance and propriety.

219. The construction of chimney-shafts, as regards the operation of discharging the smoke to the best advantage, will have very great influence on their general appearance. For, as the smoke ascends in the funnel, it will become more and more cool, and will therefore loose its buoyancy; or that the degree of heat which the smoke contains, as it passes equal sections of the funnel, will be continually diminished, and hence, in order to preserve an equal degree of

velocity in every point of its ascent, the funnel must be continually contracted as it rises. Hence the use of chimney-pots, in order to contract the upper part of the flue, and thus to give the current of hot air a greater degree of velocity, and thereby to prevent the rush of the cold air from descending into the funnel. But, as chimney-pots disfigure the appearance of a building, the general effect will be greatly improved by making a separate shaft for every funnel. These shafts may be constructed in the same style of architecture as the building, and be made ornamental in the highest degree.

220. CHIMNEY-PIECES.—A Chimney-piece is an ornament in one side of a room surrounding the aperture for containing the fire; the front of this aperture is generally rectangular, and is therefore susceptible of every species of decoration which may be used upon walls around their apertures; but, as interior decorations are always near and immediately under the range of the eye, they may be made of a lighter construction than those which are used on the exterior, which require to be bold, in order to be seen with advantage at a proper distance.

221. Chimnies are of modern introduction, and therefore we have no precedents in the remains of ancient architecture, in order to direct our taste in the decoration of this construction. The ornaments of chimnies has been but little cultivated on the Continent; the celebrated Inigo Jones may be justly considered as the first in England who has introduced a good taste for this species of architectural decoration. Since his time, architects have wrought upon his original ideas, and have greatly improved the ornaments of chimney-pieces. It is generally allowed at the present time, that the inhabitants of the British empire far excel those of other nations in such compositions.

222. GRECIAN MOULDINGS.—Grecian mouldings are those of which the profiles are formed by the curves of conic sections, particularly those of the ellipse and hyperbola. In every moulding there is to be considered the two extremities, the curvature is always regulated by a tangent at one extremity, and a tangent at some intermediate point.

223. A Grecian ovolo, when used in any part of the entablature, is generally the curve of an ellipse; but, when used in the capitals of Doric columns, the curve of the moulding is that of an hyperbola.

224. *To describe a Grecian ovolo as a portion of an ellipse, given two tangents equal and parallel to two conjugate diameters, the points of contact being the extremities of the diameters, one of them at the lower extremity of the moulding, and the other at its greatest projection.*—In the ovolo, *figures* 1, 2, 3, *plate* XXV, the two tangents BC, CD, respectively to two conjugate diameters are given, B and D being the points of contact, the point B being the lower extremity, and D the point on which the moulding has its greatest projection. Draw BA and DA respectively parallel to CD and CB, meeting each other in the centre A. Prolong BA to E, making AE equal to AB, and divide AD and CD each into a like number of equal parts. Draw right lines from E, through the divisions of AD, intersecting right lines drawn from B to the corresponding divisions in CD, in the points *a*, *b*, *c*, &c., and these are points in the curve.

225. *To describe the Grecian elliptic ovolo, figures* 4 *and* 5; *having given two tangents,* CB *and* C*p, the point* B *being the lower extremity of the curve, and the extremity of a semi-axis of the ellipse, and* p *being the point of the greatest projection of the curve.*—Draw B *b* perpendicular to BC, and join B*p*. Bisect B*p* in *l*, and draw C *l*. Prolong C *l* to meet B *b* in the point A, and through A draw A *q* parallel to BC. From the point *p*, with the distance AB, cut the right line A *q* in *r*; draw *p r* and prolong *p r*, to meet B *b* in *s*. Make A *q* equal to *p s*; then, with the semi-axis A *q* and AB, describe the curve B *k p q* G, which will be the ovolo required.

226. Grecian mouldings may also be described by the ordinates of the arcs of circles perpendicular to their chord, and transferring them, on the contrary side, upon ordinates which are parallel to the fillets, as in *figures* 6 and 7; in which a bare inspection of the figures will make this process sufficiently plain. These may be applied in capitals, bases, cornices, &c. The most elegant forms of mouldings are those where the point of contact at the lower extremity of the curve is the extremity of the semi-axis minor, as in *figures* 4 and 5.

APPENDIX TO ORNAMENTAL MASONRY,

WITH A DESCRIPTION OF ILLUSTRATIVE PLATES TO THE PRECEDING CHAPTER.

227. *Plate* XXVI. *fig.* 1, exhibits the form of a Balustrade and Parapet. The compartment, on the right hand, is filled with balusters in the usual manner (*art.* 180). As there are various modes of decorating parapets, by way of variety we have here shown two other designs in the same range: the middle compartment is panelled; but as this mode of decoration exhibits too much the appearance of joiners' work, the plain surface may be left without sinking, as was generally the practice of the ancients. The compartment, on the right hand, is ornamented with arches, perforating the thickness of the naked surface. This manner of decoration produces a very beautiful aerial effect on the eye, and very proper for the termination of a wall.

A rectilineal termination has, however, at all times, been thought too abrupt, and it has been generally desirable to break the right line which terminated the walls of an ornamented building, in order that it might associate gradually, and become insensibly aerial. Hence, in Greek architecture, the antifixa, which was at first used as an ornament, in order to cover the ends of the joints of the tiles, was, from the good effect it produced, afterwards used as terminations in other situations, where the ends of the tiles could not come: in Roman architecture, the tops of buildings were frequently decorated with pedestrian and equestrian statues, and sometimes with an ornament similar to the Greek antifixa; and, in Gothic architecture, the tops of walls were generally decorated with pinnacles, which were afterwards surmounted by finials. At the restoration of architecture in Italy, the Italian architects invented the balustrade. The dis-

position of the architects of the present day, with regard to the termination of their buildings, seems to be that of imitating the style of the ancients, and of Gothic architecture, each in its native purity.

228. *Figures* 2, 3, 4, 5, and 6.—Balusters to a large scale of several forms and proportions, in order to exhibit the parts distinctly. *Fig.* 2, exhibits a baluster with the profiles of the rail and plinth. The proportions of the heights of the members are as in *art.* 209; the thickness of the belly and breadth of the plinth are each one-third of the entire height of the baluster itself; and *fig.* 3, is the same baluster seen in front.

229. *Figure* 4, exhibits two balusters of somewhat lighter proportion than *figures* 2 and 3, the proportion of the parts in the height being the same; but the diameter of its greatest circle, and the side of the plinth, are each to the entire height of the baluster, as 2 to 7. These two balusters have an interval between their greatest circles, or thickest parts, equal to one-third of the side of the plinth of each base. The slightest proportion of single-bellied balusters may be that in which the diameter of the greatest circle of the belly is to the entire height, as 1 to 4.

230. *Figure* 5, exhibits two double-bellied balusters, recommended by Sir William Chambers for windows, terraces, and fences. In these, the thickness of the belly at the thickest part is one-fifth of the entire height of the baluster, and the interval between them is one-half of the diameter of the thickest part. All these balusters are of the Paladian form.

231. As balusters are not found in classic architecture, and as they are yet susceptible of various improvements in their contour, some attempts have lately been made to introduce small columns in their place, in various buildings of the metropolis. The desirable object of improving their form does not yet seem to be effected; the attempt is, however, laudable, and there is no doubt but future efforts will accomplish the desideratum required. *Fig.* 6, is a design for a fancy baluster, the shaft is surrounded with a series of reeds, which rise from the thickest part of the belly, and terminate below the annular sinkings under the capital.

232. *Figures* 7, 8, and 9, exhibit various forms of rustics, by means of a section and elevation to each kind. *Figures* 7 and 8 are those described *art.* 184. *Fig.* 7, exhibits part of the faces of two rustics, with a square joint between them; and *fig.* 8, exhibits a part of each face of two rustics, with a bevel joint between them. *Fig.* 9, exhibits another form for the joint between two rustics, in which the arris is rounded. These forms of rustics were taken from a building in Paris, near the Rue de Pinon, of which the elevation is *fig.* 10.

233. *Plate* XXVII. exhibits various designs for chimney-shafts, by means of a plan and elevation to each design, see *art.* 218. The design, *fig.* 1, is formed by a series of stunted columns isolated from each other, but all connected together by an intermediate part between the abacus of any one and that of the next adjacent one; these columns stand upon a plinth which is supported upon a pedestal, the plinths are not separated, but have a small recess between every two of them, in order to mark each distinctly. The plan is a horizontal section,

immediately under the shaft, or in the plane of the tops of the plinths. The series of columns may be continued to any number, which, being greater, the effect will be the more imposing.

234. *Fig.* 2, a design for a chimney-shaft in the form of an attic, which is decorated with a series of pilasters, and the intervals have chamfered recesses between them, in order to increase the contrast of light and shade. The elevation is shown at No. 1, and the plan at No. 2.

235. *Fig.* 3, is another design, in which arches splayed from the fronts are introduced, in order to lighten the appearance of the construction. The elevation is shown at No. 1, and the plan at No. 2, which is taken in the horizontal plane at the bottom of the arches. The funnels have each a separate head, and the angles are cut away by splays, so as to form in the middle of the first neck a complete octagon, and all the horizontal sections above into regular figures of eight sides each.

236. *Fig.* 4, exhibits the design for the termination of a stack of chimneys in the Gothic style of architecture. Our domestic buildings, in the Gothic style, exhibit many beautiful forms and ideas for the designs of chimney-shafts.

237. *Plate* XXVIII. *fig.* 1, exhibits another design in one single shaft; No. 1 shows the elevation, No. 2, the plan, and No. 3, a profile or section of the same. *Fig.* 2, is a profile of the upper mouldings of the chimney-shaft, *fig.* 4, in the preceding plate (being *plate* XXVII).

238. To describe the eyes and points of a Gothic arch, *fig.* 3, let the ares $a\,b$ and $c\,d$, described from the centre g, be the two edges of the cavetto next to the glass upon one side of an aperture or compartment. Then, whatever be the number of points the side of the arch will admit of, we must find such a distance $c\,e$, in the straight line $g\,h$, as will divide the arc $e\,f$, described also from the centre g, with the distance $g\,e$, (intercepted between the horizontal line $h\,g$, and the perpendicular line $k\,b$, bisecting the aperture,) into twice as many equal parts as the points are in number, and this must be done in such a manner as will leave the points of sufficient substance. Thus let it be required to have three eyes and three points, we must describe the arc $e\,f$ at such a distance as $c\,e$ from the arc $c\,d$, that $c\,e$ may divide the arc $e\,f$ into six equal parts, beginning at the point f in the perpendicular $k\,b$, and making the lower extremity of the sixth part to terminate in the given straight line $h\,g$. The first centre is the point f, by which opposite parts of the first eye is described; the second centre is the point 2, by which the second eye is described; and thus the first point completed, the third centre is the point 4, by which the third eye is described, and the second point is completed; and the last centre is the point c, by which the half-eye or hollow, and the side of the third point, is formed. From the same centres f, 2, 4, e, are described the ares $s\,r$, $r\,q\,n$, $n\,m\,l$, and $l\,a$. In the execution the ares $s\,r$, $r\,q\,n$, $n\,m\,l$, and $l\,a$, are very frequently in a plane parallel to the plane of the fillet of which the edge is $a\,b$, but the plane which contains the ares $s\,r$, $r\,q\,n$, $n\,m\,l$, and $l\,a$, recedes at a small distance from the plane of the same fillet of which the edge is $b\,a$. The curve lines, $s\,r$, $v\,q$, $q\,u$, $u\,m$, $m\,t$, and $t\,a$. are the sunk edges. These edges continually recede from the points s, ,

m, a, to the points *e, u, t,* in which they recede the most. The triangular parts *s v r, q r v, q n u, m n u, m l t, a l t,* are portions of a convex surface. The spaces between the concentric arcs re present concave surfaces.

239. *Fig.* 4, a Gothic window in three compartments. In this the mullions of the head-work intersect each other. To form such a window, the extreme breadth over the fillets is divided into three equal parts, and vertical lines are drawn through the points of division; these vertical lines are the bisecting lines of the breadths of the fillets, and are prolonged until they meet the base line of the large arch which springs from the jambs of the window.

Then, whatever be the radius of the two side-arches springing from the jambs, the same radius must be used for the corresponding parts of the arches which terminate the upper extremities of the compartments; hence, whatever be the form of the extreme side-arches, the ramifications of the mullions will have arches of the same form: all the corresponding parts of these arches may therefore be wrought by the same moulds. The two middle ramifications intersect each other, and form symmetrical quadrilaterals with the adjacent ramifications, forming the heads of the extreme compartments. In each of these quadrilaterals, the opposite eyes and points are all symmetrical with regard to the vertical lines bisecting the breadth of the fillets.

Each of the three arches over each compartment is described in the same manner as shown for *fig.* 3 The eyes and points in each of the quadrilaterals must be formed by the eye. In all these the straight line which bisects each of the points, must always be in a direction of the radius of curvature of the various arcs described. The moulding over the head, which returns upon the face of the wall, is termed the *hood* or *label-moulding*. *Fig.* 5, is a section of the label to a larger scale. *Fig.* 6, is an enlarged section through one of the munnions. In this the curves, both within and without, are equal and similar, and both sides are symmetrical, as regards their lines of symmetry, which are vertical.

The two notches, one upon each side, are taken out, in order to receive the glass-frame, which being inserted, the frame is fixed with cement, by which the complete surface of the hollow and the straight part perpendicular to the glass is symmetrically formed to the same section, as the part on the outside of the glass-frame. The transome of this window is plain, but it may be ornamented in the same manner as the heads of the three vertical compartments; but with this difference, that each head ought to be similar to the arches which spring from the jambs, and not to those which spring from the munnions.

When the ornaments of any head consist of three eyes, the head is called a trefoil-head; and when it consists of five eyes, it is called a *cinquefoil-head; figures* 7 and 8 are profiles of different forms for labels.

240. *Plate* XXIX containing Grecian and Roman windows (*art.* 192). *Fig.* 1, the elevation of a window, with an architrave and sill surrounding the aperture. The architrave has a break upon each side immediately under the lintel, as was frequently done in Greek and Roman archi-

tecture. The sill of the window is something broader than the architrave. The sills of ancient buildings have no relation to those of common buildings, which are generally of one thickness in their height, and usually about $2\frac{1}{2}$ inches, when the aperture is without an architrave, or without any other ornament on the three remaining sides. Windows of this description are appropriate to buildings of one story, slightly decorated in the other parts. The elevation of the window here given is in imitation of that in the temple of Erectheus, at Athens.

241. *Fig.* 2, the elevation of a window, surrounded with an architrave on the two vertical sides and over the head; the two vertical sides of the architrave are flanked with plain pilasters, and the horizontal part of the architrave is surmounted by a frieze and cornice, of which each extremity is supported by a console. The breadth of the sill is equal to that of the architrave. The profile of the ornaments, which shows the end elevation of the cornice and the side of the console, is exhibited at *fig.* 3. Such forms of windows may be applied to the principal stories of buildings.

242. *Fig.* 4, elevation, consisting of the dressings of a window, of which the upper part is a regular entablature, surmounted with a pediment. The architrave round the three sides, and the sill, being very nearly similar to those in *fig.* 1, as well as the aperture, which is wider at the bottom than at the top. These trapezoidal apertures were used both by the Greeks and Romans; but not in imitation of those which are to be found among the Egyptians: for, as it has already been observed that, in the remaining antiquities of Egypt, the jambs of all apertures are vertical, and are therefore parallel to each other; and consequently, because the sills and soffits are level, the apertures of Egyptian buildings are rectangular. The simple ornament, however, which forms a kind of architrave, is wider at the bottom than at the top.

243. *Fig.* 5, exhibits the dressings of an arched window, the ornaments consist of pilasters, one on each side of the aperture, supporting an archivolt, concentric with the semi-circular head of the window. Though the ornaments of this window are Roman, the combination is Gothic.

244. *Plates* XXIX.*a*, XXIX.*b*.—Decorations for chimney-pieces. In these ornaments, for want of original precedents, we are under the necessity of applying such ornaments to the apertures of fire-places, as we might suppose that the ancients would have done, had they used such recesses in their walls for the warming of rooms.

245. *Plates* XXIX.*c*, XXIX.*d*.—Designs for monuments. *Plate* XXIX.*c*, is a design for a monument in the florid style of Gothic architecture. In the Grecian style of architecture, the fillets and faces of architraves are, in ancient and modern works, parallel to the face of the building; but, in Gothic architecture, the architrave is neither parallel nor perpendicular to the face, but at an angle generally inclined at 135 degrees. In the design before us, though truly Gothic, may be traced the features of genuine Greek architecture, with the exception of the architrave, and the ornaments which surround the arch. The sill, instead of being plain, is decorated with Gothic mouldings, and support pilasters, which, instead of being plain, are orna-

mented with panels, terminating with eyes and points, as usual in this species of architecture. The pilasters support a frieze and cornice. The frieze is decorated with square pateras of various forms. It must, however, be observed here, that the pilasters have no apparent break at the top, but are joined together by a part extending over the head of the architrave in the same plane with the styles and heads.

The cornice on the top is surmounted with a tablet filled with diagonal panels, and the panels are surrounded with points and eyes. The cornice which terminates this tablet has a sharp-pointed pediment in the centre.

One peculiarity in Gothic architrave mouldings is, that the outer mouldings are frequently carried perpendicularly, and mitre with a corresponding horizontal part, and thus forming three sides of a rectangle; and the adjacent mouldings in the middle parts of the architrave are carried from the spring round upon each jamb, and meet together over the centre of the aperture, and thus form a Gothic arch. The mouldings of the architrave, which form the three sides of a rectangle, and the Gothic curves, contain triangular spaces called spandrils, which are generally filled with quatrefoil-arcs and small panels upon each side. The under side of the arch is often decorated with cusp-panels. In this example, besides the cusp-panels, the inner margin terminates in eyes and points.

Plate XXIX. *d*, is a design of a monument in the Grecian style of architecture, which, from a degree of neatness and plainness, exhibits a striking contrast when compared with the Gothic.

CHAPTER IX.

VALUATION OF MASONS' WORK.

246. To all the distinct parts of Masons' work, a certain value is assigned for the labour and expense of erection and execution.

Masons' work is generally measured with two rods, about five feet long, each divided into feet, halves and quarters of feet, and sometimes inches; but the common rule is generally applied to measure the smaller fractions. Stone-work, exceeding two inches in thickness, is valued by cubic feet; if less than two inches, it is valued as slabs, by the superficial feet. All kinds of ornamental work, as groovings, flutings, joints, rebats, throatings, copings, &c., are valued by the running foot. The dimensions are put down in a book. It often happens that there are several pieces of the same size, and these are marked down, as well as the nature of the stone, and the species of labour required for working it.

Thus every portion of material and labour is accurately ascertained. After this has been done, a loose sheet of paper is ruled into as many columns as there are species of work, which is written over the head of each: as, beginning with cube of Portland-stone, is placed in the column under that head; and the same for plain-work, sunk-work, moulded-work, and each species of running-work, separately. They are cast up at the bottom of each column, and from them made out into bills, beginning with cubes, then superficies; and, lastly, ornamental-work. For measuring, cubing, squaring, valuing, and finishing the account, surveyors are allowed two and a half per cent. on the gross amount.

247. *Plain-work* consists merely in the cleaning up of its surface, and all is measured which is seen.

248. *Sunk-work* is that which has been partly chiselled away, as the tops of window-cills, &c.

249. *Moulded-work* is that which is formed into various forms on the edges, as cornices, architraves, &c. The dimensions of moulded-work are ascertained by girting the whole round with a piece of tape, over and into all its several parts; the length of the tape will give the width of the moulded-work, and then taking its length, and squaring them together, the superficial quantity of moulded-work will be given. A distinct valuation is attached to each kind of labour; and, as this varies in different places, it would be of little use to insert any here. In London, however, the prices are uniform for each separate kind.

CHAPTER X.

AN EXPLANATION OF TERMS, AND DESCRIPTION OF TOOLS, USED IN MASONRY.

Abutment.—A term used in masonry, which implies one of the props at the springing of an arch, which is supported by an abutment at each end. The *abutments* of a bridge mean the walls adjoining to the land, which support the ends of the extreme arches or roadway.

Aperture.—An opening through a wall, &c. which has, generally, four straight sides, forming a rectangle; of these four sides. two are perpendicular to the horizon, and the other two parallel to it; the vertical stones are called *jambs*. The lower horizontal stone is called the *cill*, and the upper one the *head* or *lintel*. Sometimes, instead of a lintel, an arch is introduced, in order to support the incumbent wall. If the head be an arch, the aperture is called an *arcade*. Apertures may be entirely cylindrical; but these are not very frequent.

Arch.—Part of a building suspended over a hollow, between abutments at the extremities, and concave towards the area, over which the arch is suspended.

Archivolt, is the architrave round an arch, formed into mouldings concentric with the intrados upon the upper sides of the arch-stones in the face of the work; by the *archivolt* is also understood the whole set of arch-stones that appear in the face of the work.

Ashlar.—A term applied to common or free-stones, as they come out of the quarry. By *ashlar* is also meant the facing of squared stones on the front of a building. If the work be so smoothed as to take out the marks of the tools by which the stones were first cut, it is called *plane-ashlar:* if figured, it may be *tooled ashlar*, or *random tooled*, or *chiselled*, or *boasted*, or *pointed*. If the stones project from the joints, it is said to be *rusticated*.

Banker.—The stone bench on which work is cut and squared.

Banquet.—The raised foot-way adjoining to the parapet on the sides of a bridge.

Battardeau.—See *Coffer-dam*.

Batter.—The leaning part of the upper part of the face of a wall, which so inclines as to make the plumb-line fall within the solid.

Beds *of a Stone*.—The parallel surfaces which intersect the face of the work in lines parallel to the horizon, and meet two and two in every pair of adjacent stones.

In arching, the beds were formerly called *summerings;* but now, with more propriety, *radiations* or *radiated joints*.

Bond.—That regular connexion, in lapping the stones upon one another, when carrying up the work, which forms an inseparable mass of building.

Butment.—See *Abutment*.

Caisson.—A chest of strong timber in which the piers of a bridge are built, by sinking it, as the work advances, till it comes in contact with the bed of the river, and then the sides are disengaged, being constructed for that purpose.

Centres.—The frame of timber-work for supporting arches during their erection.

Coffer-dam, or Battardeau.—A case of piling, without a bottom, constructed for inclosing and building the piers of a bridge. A coffer-dam may be either single or double, the space between being filled with clay or chalk, closely rammed.

Drag.—A thin plate of steel indented on the edge, like the teeth of a saw, and used in working soft stone, which has no grit, for finishing the surface.

Drift.—The horizontal force of an arch, by which it tends to overset the piers.

Extrados *of an Arch*.—The exterior or convex curve, or the top of the arch-stones. This term is opposed to the *Intrados*, or concave side.

Extrados *of a Bridge*.—The curve of the road-way.

Fence-Wall.—A wall used to prevent the encroachment of men or animals.

Footings.—Projecting courses of stone, without the naked superincumbent part, and which are laid in order to rest a wall firmly on its base.

Headers.—Stones disposed with their length horizontally, in the thickness of the wall.

Jettee. The border made around the stilts under a pier.

Impost or Springing.—The upper part or parts of a wall employed for springing an arch.

Intrados.—The concave surface, or soffit, of an arch.

Joggled Joints.—The method of indenting the stones, so as to prevent the one from being pushed away from the other by lateral force.

Key-Stones.—A term frequently used for *bond-stones*.

Key-Stone.—The middle voussoir of an arch, over the centre.

Key-Stone *of an Arch.*—The stone at the summit of the arch, put in last for wedging and closing the arch.

Level.—Horizontal, or parallel to the horizon; or, a straight line perpendicular to a plumb-line.

Naked, *of a Wall.*—The vertical or battering surface, whence all projectures arise.

Off-set.—The upper surface of a lower part of a wall, left by reducing the thickness of the superincumbent part upon one side or the other, or both.

Parapets.—The breast-walls erected on the sides of the extrados of the bridge, for preventing passengers from falling over.

Paving.—A floor, or surface of stone, for walking upon.

Piers *in Houses.*—The walls between apertures, or between an aperture and the corner.

Piers *of a Bridge.*—The insulated parts between the apertures, for supporting the arches and road-way.

Piles.—Timbers driven into the bed of a river, or the foundation of a building for supporting a structure.

Pitch *of an Arch.*—The height from the summit of the arch to the chord extended between the springing-points.

Push *of an Arch.*—The same as *Drift;* which see.

Quarry.—The place whence stones are raised.

Random Courses, *in Paving.*—Unequal courses, without any regard to the arrangement of the joints.

Shoot *of an Arch.*—The same as *Drift;* which see.

Span.—The span of an arch is the extension between the two springings.

Sterlings.—A case made about a pier of stilts, or piles, in order to secure it. See the following article.

Stilts.—A set of piles driven into the bed of a river, at small distances, with a surrounding case of piling driven closely together, and the interstices filled with stones, in order to form a foundation for building the pier upon.

Stretchers.—Those stones which have their length disposed horizontally in the length of the wall.

Through Stones.—A term employed, in some countries, for bond-stones.

Thrust.—The same as *Drift;* which see.

Tools *used by Masons.*—The masons *Level, Plumb-Rule, Square, Bevel, Trowel, Hod,* and *Compasses.*

The *Saw* used by masons is without teeth, and stretched in a frame nearly resembling the joiner's saw-frame. It is made from four to six feet, or more, in length, according to the size of the slabs which are intended to be cut by it. To facilitate the process of cutting slabs into slips and scantlings, a portion of sharp silicious sand is placed upon an inclined plane, with a small barrel of water at the top, furnished with a spigot, which is left sufficiently loose to allow the water to exude drop by drop; and thus, by running over the sand, carries with it a portion of sand into the kerf of the stone. The workman sits at one side of the stone, and draws the saw to and fro, horizontally, taking a range of about twelve inches each time before he returns. By this means, calcareous stones of the hardest kinds may be cut into slabs of any thickness, with scarcely any loss of substance. But, as this method of sawing stone is slow and expensive, mills have been erected in various parts of Great Britain, by which the same process is performed at a much cheaper rate, and in some of these mills every species of moulding upon stone is produced.

Masons make use of many *chisels,* of different sizes, but all resembling, or nearly resembling, each other in form. They are usually made of iron and steel welded together; but, when made entirely of steel, which is more elastic than iron, they will naturally produce a greater effect with any given impulse. The form of masons' chisels is that of a wedge, the cutting-edge being the extremity of the vertical angle. They are made about eight or nine inches long. When the cutting-edge is broader than the portion held in the hand, the lower part is expanded in the form of a dove-tail. When the cutting-edge is smaller than the handle, the lower end is sloped down in the form of a pyramid. In finishing off stone, smooth and neat, great care should be taken that the arris is not splintered, which would certainly occur, if the edge of the chisel were directed outwards in making the blow: but, if it be directed inwards, so as to overhang a little, and form an angle of about forty-five degrees, there is little danger of splintering the arris in chipping.

Of the two kinds of chisels which are the most frequently made use of, *the tool* is the largest; that is to say, in the breadth of its cutting-edge; it is used for working the surface of stone into narrow furrows, or channels, at regular distances; this operation is called *tooling,* and the surface is said to be *tooled.*

The *Point* is the smallest kind of chisel used by masons, being never more than a quarter of an inch broad on its cutting-edge. It is used for reducing the irregularity of the surface of any rough stone.

The *Straight-Edge* is similar to the instrument among carpenters of the same name; it being a thin board, planed straight upon one edge, to point out cross-windings and other inequalities of surface, and thus direct the workmen in the use of the chisel.

The *Mallet* used by the mason differs from that of any other artisan. It is similar to a dome in contour, excepting a portion of the broadest part, which is rather cylindrical. The handle is rather short, being only just long enough to be firmly grasped in the hand. It is employed for giving percussive force to chisels, by striking them with any part of the cylindrical surface of the mallet.

The Hammer used by masons is generally furnished with a point or an edge like a chisel. Both kinds are used for dividing stones, and likewise for producing those narrow marks or furrows left upon hewn-stone work which is not ground on the face.

Vault.—A mass of stones so combined as to support each other over a hollow.

Under Bed *of a Stone.*—The lower surface, generally placed horizontally.

Upper Bed *of a Stone.*—The upper surface, generally placed horizontally.

Voussoirs.—The arch-stones in the face or faces of an arch; the middle one is called the *key-stone.*

Wall.—An erection of stone, generally perpendicular to the horizon; but sometimes *battering,* in order to give stability.

Walls are of various descriptions, and, on some occasions, they are denominated from the nature of the plan, whatever may be the form of the profile; and thus, generally speaking, a wall may either be straight or curved. A straight wall is that in which the two edges of its plan (supposed to be horizontal) is a straight line; and a curved wall is that of which the two edges of its plan (supposing these edges contained in a horizontal plane) are curves. Walls are also denominated from the form of their surface. A plane wall is a straight wall, in which the sides of the vertical section are straight lines, either perpendicular to the horizon or battering. A cylindrical wall is a wall of which the plan is a curve, and of which the vertical sections are right lines perpendicular to the horizon. However, in order that a wall may be called a cylindrical wall, it is only necessary that one side may be a cylindrical surface. A conical wall is that of which the plan is a curve, and the rising line of the profile a battering right-line.

BOOK II

BRICKLAYING

INTRODUCTION.

250. BRICKLAYING is the art of Building with Brick, or of uniting them, by cement or mortar, into various forms for particular purposes.

251. Before we enter into the descriptive and technical explanations of this useful art, it will be advantageous to investigate the nature and properties of the various kinds of bricks that have been made, not only in this country, but also in those countries where the genial temperature of the climate permitted the use of bricks manufactured in a more simple manner than can possibly be adopted in this country, where alternate frost and thaw are prevalent.

Bricks may not improperly be considered as a kind of artificial stone: but, before we enter into a description of the various kinds that are produced by the process of burning, or partial vitrification, it will be proper to notice the nature of those that, in warm climates, are made sufficiently durable by being dried in the sun.

As clay is the material that has at all times been used for making bricks, some of its peculiar properties require to be noticed in this place, in order to show the propriety of certain operations that are necessary in the manufacture of that most necessary article.

Alumina is one of the primitive earths, and constitutes the plastic principle of all clays, loams, and boles, on account of its being obtained in the greatest degree of purity from alum. It has obtained the name of Alumina; and it should be here understood, that the various properties which we find in clays, cannot arise from any variation in the quality of the Alumina which constitutes the base of all clays, but from the admixture of silicia, iron, lime, mica, feltspar, &c., which, being combined or mixed with them in various proportions, renders them peculiarly valuable for certain purposes, when they are properly selected and prepared by the processes peculiar to certain manufactures.

If we carefully observe the various strata of clay, as they lie in their natural beds, we shall find that all of them permit water to percolate through them with great facility, both ascending and descending, and hence springs are by no means uncommon where clay abounds: but if clay of that plastic kind, suitable for the manufacture of bricks and various kinds of pottery, be dug from its native bed, and exposed to the action of the atmosphere, and also to the degree of temperature producing frost, it will be disintegrated in a considerable degree, and rendered, by

such minute division of its substance, more fit for the operation of mixing with other substances or materials necessary in certain cases, and which will be hereafter described.

When clay has been treated in the manner above described, it must be moistened sufficiently with water, and be well beaten or wrought together without any admixture of other materials; and if it be also well compressed together, it will attain such a degree of solidity by compression as will render it capable of resisting the passage of water through it in a considerable degree: its filtering or percolating properties being by these means very nearly destroyed. It is in this state that it should be used as a covering to arches forming the vaults in front of houses, to prevent the water from passing through the brick-work, and thereby destroying any articles usually deposited therein.

If clay be tempered in this manner, and when it has obtained a certain degree of dryness, and it be firmly compressed in a mould either by absolute weight or percussion, and if it be afterwards well dried in the air, with the addition of the heat of the sun, bricks so made will be found sufficiently hard to resist the effects of great pressure; hence walls may be constructed in warm climates that will be found very durable. It is stated by ancient authors upon this subject, that such bricks were seldom used until they had been submitted to the process of drying for two years at least.

Vitruvius, in describing the nature and properties of semi-dried bricks, states that such could not be used by the Romans within the city, for the laws did not permit any walls in public places to be made thicker than one foot and a half; whereas sun-dried bricks of that thickness would not support more than one story.

When Augustus boasted that he found Rome of brick, and left it of marble, it is evident that he must have meant sun-dried bricks; for it is well known that the temple of Peace, the Pantheon, and many other buildings, were constructed of bricks, hardened by the process of burning.

The use of bricks is of the greatest antiquity; the cement used in the earliest periods being a kind of bitumen. In this manner the city of Nineveh was built by Nimrod, and the justly celebrated walls of Babylon, estimated by the Greeks as worthy to be numbered among the wonders of the world, were erected of the same materials.

The method of making unburnt bricks, by the Egyptians of modern times, appears to be the same that was adopted in the oldest time; namely, that of mixing straw with tempered clay, in order to prevent the mass from cracking. This is proved by examining the remains of a pyramid formed of these bricks, the name of which is stated by Pocoke to be "Klouber-el menshich." The remains of this immense structure were found to be 150 feet high.

252. Having so far explained the nature of sun-dried bricks, we shall now call the attention of our readers to that of kind of bricks that are hardened by the action of fire. In most cases, fine pure clay is found to make the most durable bricks, provided proper care be taken to temper the clay well, and also that they be well dried and sufficiently burned. Many of the

bricks or tiles made by the Romans while in this country are still in existence: a portion or fragment of an arch may be seen at Leicester, composed of Roman tiles, which retain their original hardness; and those appear to be made of clay, containing a large portion of the oxyde of iron, the colour being red. They have evidently been burned, and most likely with wood as fuel, coal being most probably either unknown, or very little used at that period. This red kind of brick is very generally known over England, as most of our clays are, more or less, combined or impregnated with oxyde of iron; that being the material that imparts the red colour to earths when burned.

Bricks of this description are usually burned in kilns, in which case the fire completely surrounds them, and the equality of heat that can be obtained by these means produces a greater equality in the articles so burned, than can be obtained by burning in clumps, which is the method that is most frequently adopted around London.

253. The bricks of the antients were of various forms and sizes, and their triangular bricks were peculiarly adapted to certain figures, but modern bricks, of English make, are commonly of one form, 9 inches long, by $4\frac{1}{2}$ broad, and $2\frac{1}{2}$ deep.

254. Bricks, near the metropolis, are made of a species of clay or loamy earth, either pure or with various mixtures; they are shaped in a mould, and, after some drying in the sun or air, are burnt to an uncertain degree of hardness. The more pure the earth of which they are formed, the harder and firmer the bricks will be. The bricks generally known to our modern builders are of several sorts: that is to say, *Marls*, of two qualities, *Gray-Stocks*, and *Place-Bricks*, besides two or three foreign kinds, occasionally imported. Bricks vary in quality, according to the quality of the material of which they are composed, the manner in which the clay is tempered, and the diffusion of the heat while burning.

The finest kind of Marls, called *Firsts*, are those usually selected for arches over doors and windows: those less fine, called *Seconds*, are commonly used for the fronts of buildings. The Gray-Stocks are of the next quality, and are generally of good earth, well-wrought, with little mixture, sound, and durable. Place-Bricks are too frequently poor and brittle, badly burnt, and of very irregular colour. *Burrs* or *Clinkers* are such as are so much overburnt as to vitrify, and run too or three together.

Red Stocks and the *Red Bricks*, called also, from their use, *Cutting Bricks*, owe their colour to the nature of the clay of which they are made, containing much oxyde of iron; this is always used tolerably pure, and the bricks of the better kind are called by some *Clay Bricks*, because they are supposed to be made of nothing else.

255. Many of the clays near London are so largely mixed with gravel, that it is found necessary to have recourse to the process of washing, and for this purpose, clay-mills are used, in which the clay when dug is placed, and plenty of water being poured upon it, the mass is agitated and separated in a circular trough, and when the gravel has subsided to the bottom, the fluid is permitted to run off into pits where the superfluous water drains from it; and when

it has obtained sufficient consistency, the materials necessary to be mixed with it are then laid upon the surface, and mixed with it by the manual operation of tempering.

In many parts of the country, clay mixed in certain proportions with cow-dung, small coals, saw-dust, and other combustible materials, is used as fuel, when made up into balls and dried in the sun or air; and when masses of these are laid together and kindled, they are found to consume, and offer a very convenient mode of using the refuse of coal and other materials. The principle of making bricks near the metropolis is so analogous to this method of preparing fuel, that we have thought it right to call the attention of our readers to the subject, in order that the circumstances of burning bricks in clamps may be better understood. The very great consumption of coals in London, and its environs, produces an immense quantity of cinders and ashes, which are collected, and when sifted to separate the cinders or breeze (as they are technically called) from the ashes or soil, they are sold to the brick-makers to mix with their clay, and also to burn their bricks with. About one-fourth or one-sixth, as the case may be, of the soil or ashes, is usually mixed with the clay for making the common gray-stock, and also the *place-bricks*, and the mixture is in such a plastic state as to enable the workman to fill his mould, by merely letting it fall with some degree of force into it, and the superfluous part is removed with a wooden straight-edge, and so little is it compressed that it will readily drop out of the mould, upon either hand-board used to remove it upon. In this state it is laid upon others, that have attained some degree of dryness, and thus rendered fit to be placed in the clamp to be burned.

A little consideration will shew that bricks so made are very similar to the clay-balls above named; that is to say, they are combined with materials calculated to burn themselves, in a great degree, when properly kindled: for if the ashes or soil, as it is technically called, be carefully examined, it will be found to contain a large portion of the small coals that have fallen through the grates, and which has never been submitted to the action of combustion at all, and also a large portion of very minute cinders, quite capable of supporting combustion, and thereby assisting to burn, or partially vitrify, the mass of which they form so large a part.

256. While treating of this department of brick-making, it may be well to call attention to the imperfect mode of moulding them, which is owing entirely to the very wet state in which the clay is used; for, in consequence of this circumstance, a shrinking takes place to such an extent, as to render it almost certain, that if the mass be bound in the least degree as it lays to dry, it will materially separate, and become cracked before it is carried to the clamp; whereas if the mass, when properly mixed, was used much drier, and forced into the mould by mechanical means, the bricks so formed would be much more solid and ponderous, and when burned, would be found to be without cracks, and, consequently, more durable and valuable in every respect.

In packing bricks so made into the clamp, it is found necessary to lay a course of bricks already burned at the bottom, in a very open manner, so that the spaces between may form flues

or passages for the air; and then upon these the first layer or course of unburned bricks are laid, having on them a layer of breeze, four or five inches thick; other courses are laid on these, diminishing the quantity of breeze, or cinders, until a very thin sprinkling is laid between the upper courses, which is generally found sufficient for the purpose.

When a clamp of bricks are burned in this way, it will be found that, for want of sufficient means to regulate the draught, some of them are completely vitrifyed, while others have received so small a degree of heat, that they are very little harder than dried clay; while those which have received a due degree of heat will be found generally of a clean, sound, and good shape. Those that are fairly burned, are selected and sold under the name of *Gray-stocks;* while those that are very slightly burned are selected for *Place-bricks,* being very frequently and improperly used on the inside part of walls.

Place-bricks are usually redder than stocks, and much more soft and crumbly. Those that are partially vitrifyed lose their shape, and are sold under the name of *Burrs.* This sort of bricks lose their colour, and become, in many instances, little better than a mass of scoria: for in some cases, owing to particular circumstances, large portions of the clamp will be so completely vitrifyed that it is impossible to separate the bricks from each other, and hence very considerable loss is experienced by the manufacturer.

257. The Gray Stocks, being made of a good earth, well wrought, and soundly burned, are commonly used in the fronts of common buildings, for in the best brick-work the best marls are used; the Place Bricks, for the reasons given above, are therefore weaker and more brittle, and are introduced where they cannot be seen, and where little stress is laid upon them: the Red Bricks, of both kinds, are made of a particular earth, well wrought, and little injured by mixtures; and they are used in fine work, in ornaments over windows, and in paving. These are frequently cut or ground down to a perfect evenness, and sometimes set in putty instead of mortar; and thus set they make a very beautiful appearance.

These are the kinds of bricks commonly used by us in building, and their difference is owing to variety in the materials. The Place Bricks and Gray Stocks are made in the neighbourhood of London, wherever there is a brick-work; the two kinds of red brick, depending upon a particular kind of earth, can be made only where that is to be had; they are furnished from several places within fifteen or twenty miles of London.

258. We have already observed, that there are two or three other kinds of brick to be named, which are imported from other countries; and there is also one of the red sort of cutting brick that is of our own manufacture, which, for its excellence, deserves to be particularly mentioned; this is the Hedgerly Brick: it is made at a village of that name, of the famous earth called Hedgerly loam, well-known to the glass-makers and chymists. The loam is of a yellow-reddish colour, and very harsh to the touch, containing a great quantity of sand; its particular excellence is, that it will bear the greatest violence of fire without injury: the chymists coat and lute their furnaces with this, and the ovens at glass-houses are also repaired or lined with it.

where it stands all the fury of their heat without damage. It is brought into London for this purpose, under the name of Windsor loam, the village being near Windsor, and is sold at a high price. The bricks made of this are of the finest red that can be imagined. They are called *Fire-Bricks*, because of their enduring the fire; and are used about furnaces and ovens in the same way as the earth.

The foreign bricks above mentioned are the *Dutch* and *Flemish Bricks* and *Clinkers:* these are all nearly of a kind, and are often confounded together; they are very hard, and of a dirty brimstone colour; some of them not much unlike our Gray Stocks, others yellower. The Dutch are generally the best baked, and Flemish the yellowest. As to the Clinkers, they are the most baked of all, and are generally warped by the heat. These bricks are used for peculiar purposes; the Dutch and Flemish for paving yards, stables, and the like; and the clinkers for ovens.

The fine red cutting English Bricks are twice, or more than twice, the price of the best Gray Stocks; the Red Stocks half as dear again as the gray; and the Place Bricks, as they are much worse, so they are much cheaper, than any of the others.

The Gray Stocks and Place Bricks are employed in the better and worse kinds of plain work; the red stocks, as well as the gray, are used sometimes in this business, and sometimes for arches, and other more ornamental pieces: the fine red cutting bricks are used for ruled and gauged work, and sometimes for paving; but the red stones are more frequently employed when a red kind is required for this purpose.

259. As the colour of bricks is an object of considerable importance, some being greatly preferable to others, we shall here observe, that in London and its environs, the gray stock for external is preferred, except for very superior buildings, and there the best Marls are always used. The gray colour of the stock brick is partly produced by an external coating of a peculiar kind of sand obtained in the river Thames, about and below Blackwall. This is brought up the river in barges, and carted to the different brick-works, where it is spread out in the air to dry. Previous to the mass of tempered clay being dropped into the mould, it is well rolled about in a quantity of this sand which forms an external coating, and when the mass leaves the mould, it is laid upon a board covered with the sand, and the upper surface is also covered with it by a sieve. In this way two purposes are effected; namely, colour is given to the external surface of the brick, and, by being covered with sand, which becomes imbedded, it is in a better state to be handled or moved to the place where it is to be dried.

It must be admitted, that much of the London clay is very impure, and from an admixture with gravel, is very unfit for the purpose of making good sound bricks; but it is also evident, that the present mode of making them in so moist a state, is bad in principle and highly prejudicial in the practice. It has been suggested to make bricks with tempered clay and ashes in a much drier state, and by great compression force the materials into the mould, by which means they would obtain greater solidity and compactness previous to being dried.

Several patents have been obtained for applying machinery to this purpose, but, in using a plastic material, like tempered clay, so much difficulty was experienced in feeding the moulds, and separating the superfluous quantity of clay from the surface of the mould, so as to leave a well-formed mass therein, that they have all been given up and abandoned. Much difficulty was also experienced in protruding or delivering the compressed clay from the mould; for this could only be effected by a piston that exactly fitted the mould internally, and when so adjusted, it was found to continue in that state but a very short time, having to act continually against sand, gravel, and pebbles of all shapes and forms, which very soon destroyed those parts of the machinery where considerable accuracy was most requisite.

We must, in justice to the inventors of the various machines, declare that a more legitimate object for improvement does not offer itself to the attention of the mechanist or engineer than the one under consideration, and it is much to be lamented that success did not crown the efforts of those who made the attempt; for, having seen some of the bricks burned that were so compressed, we have no hesitation in saying, they were by far the best, both for shape, soundness, and hardness, that we had ever seen.

260. The Red Cutting Brick, or fine red, is the finest of all bricks. In some places they are not at all acquainted with this; in others, they confound it with the red stock, and use that for it; though, where the fine red brick is to be had pure and perfectly made, the difference is five to three in the sale price between that and the red stock.

The Red and Gray Stock are frequently put in gauged arches, and one as well as the other set in putty instead of mortar: this is an expensive work, but it answers in beauty for the regularity of the disposition and fineness of the joints, and has a very pleasing effect.

The fine Red Brick is used in arches ruled and set in putty in the same manner; and, as it is much more beautiful, is somewhat more costly. This kind is also the most beautiful of all in cornices, ruled in the same manner, and set in putty.

The Gray Stocks of an inferior kind are also used in brick walls.

261. The Place Bricks are used in paving dry, or laid in mortar, and they are put down flat or edgeways. If they are laid flat, thirty-two of them pave a square yard; but, if they are placed edgeways, it takes twice that number: in the front work of walls the Place Bricks should never be admitted, even in the meanest building. That consideration, therefore, only takes place in the other kinds: and the fine Cutting Bricks come so very dear this way, that few people will be brought to think of them; so that it lies, in a great measure, between the Gray Stocks and Red Stocks. Of these the gray are most used; and this not only because they are cheaper, but, in most cases where judgment is preferred to fancy, they will have the preference.

We see many very beautiful pieces of workmanship in Red Brick; but this should not tempt the judicious architect to admit them into the front walls of buildings. In the first place, the colour itself is fiery and disagreeable to the eye; and, in summer, it has an appearance of heat that is

very disagreeable; for this reason it is most improper in the country, though the oftenest used there, from the difficulty of getting gray. But a farther consideration is, that, in the fronts of most important buildings, there is more or less stone-work; now, as there should be as much conformity as can be attained between the general nakedness of the wall and those several ornaments which project from it, the nearer they are of a colour, the better they always range together; and if we cast our eyes upon two houses, the one of red and the other of gray brick, where there is a little stone-work, we shall not be a moment in doubt which to prefer. There is something harsh in the transition from the red brick to stone, and it seems altogether unnatural; in the other, the Gray Stocks come so near the colour of stone, that the change is less violent, and they sort better together. Hence, also, the Gray Stocks are to be considered as best coloured when they have least of the yellow cast; for the nearer they come to the colour of stone, when they are to be used together with it, it is certainly the better. Where there is no stone-work, there generally is wood; and this, being painted white, as is commonly the practice, has yet a more violent contrast with red brick than the stone-work: the transition is more sudden in this than in the other; but, on the other hand, in the mixture of gray bricks and white paint, the colour of the brick being soft, there is no violent change.

The Gray Stocks are now made, of prime quality, in the neighbourhood of London. The late Duke of Norfolk had the bricks brought from his estate, in that county, for building the front of his house, in St. James's-square; but the event shews that his Grace might have been better supplied near at hand, as to colour, with equal hardness.

The greatest advantage that a Gray Stock, which is the standard brick, can have, is in its sound body and pale colour; so that the principal thing the brick-maker ought to have in view, for the improvement of his profession, is the seeking for earth that will burn pale, and that will have a good body, and to see it has sufficient working. The judicious builder will always examine his bricks in this light, and be ready to pay that price which is merited by their goodness.

The utility and common practice of building all our edifices of brick, both in London and the country, arises from motives too obvious to need a definition; since it is generally considered to be much the cheapest, as well as the most eligible substance that can be invented for the purpose, both in point of beauty and duration, and inferior to nothing but wrought stone.

CHAPTER I.

ON THE NATURE AND PROPERTIES OF BRICK BOND.

262. BRICKS ARE LAID in a varied, but regular, form of connection, or *Bond*, as exhibited in *Plate* XXIX, *e*. The mode of laying them for a 9-inch walling, shown in *figure* 1, being denominated *English Bond;* and *figure* 2, *Flemish Bond*. *Figure* 3 is English Bond, in a brick and a half, or 14-inch walling; and *figure* 4, Flemish Bond, in the same. *Figure* 5 represents another method of disposing Flemish Bond in a 14-inch wall. *Figure* 6, English Bond, in an 18-inch, or two brick thick, wall; and *figure* 7, English Bond, in a two and half brick thick wall.

Figures 8, 9, 10, 11, represent courses, in square pairs, of Flemish Bond. In each pair, if one be the lower course, the other will be the upper course.

The bricks, having their lengths in the thickness of the wall, are termed *Headers*, and those which have their lengths in the length of the wall are *Stretchers*. By a *Course*, in walling, is meant the bricks contained between two planes parallel to the horizon, and terminated by the faces of the wall. The thickness is that of one brick with mortar. The mass formed by bricks laid in a radiated position, for arches or vaults, is also denominated a *Course*.

The disposition of bricks in a wall, of which every alternate course consists of *headers*, and of which every course between every two nearest courses of headers consist of *stretchers*, constitutes *English Bond*.

The disposition of bricks in a wall, (except at the quoins,) of which every alternate brick in the same course is a *header*, and of which every brick between every two nearest headers is a *stretcher*, constitutes *Flemish Bond*.

263. It is, therefore, to be understood that *English Bond* is a continuation of one kind throughout, in the same course or horizontal layer, and consists of alternate courses of headers and stretchers, as shown in the plate; the headers serving to bind the wall together, in a longitudinal direction, or lengthwise, and the stretchers to prevent the wall splitting crossways, or in a transverse direction. Of these evils the first is of the worst kind, and therefore the most to be feared.

A respectable writer on this subject has said, that the old English mode of brick-work affords the best security against such accidents; as work of this kind, wheresoever it is so much undermined as to cause a fracture, is not subject to such accidents, but separates, if at all, by breaking through the solid brick, just as if the wall were composed of one piece.

The antient brick-work of the Romans was of this kind of bond, but the existing specimens of it are very thick, and have three, or sometimes more, courses of brick, laid at certain intervals of the height, stretchers on stretchers, and headers on headers, opposite the return wall, and sometimes at certain distances in the length, forming piers, that bind the wall together in a transverse direction; the intervals between these piers were filled up, and formed panels of rubble or reticulated work (articles 70 and 71); consequently, great substance, with strength, were economically obtained.

264. It will, also, be understood that *Flemish Bond* consists in placing, in the same course, alternate headers and stretchers, a disposition considered as decidedly inferior in every thing but appearance, and even in this the difference is trifling; yet, to obtain it, strength is sacrificed, and bricks of two qualities are fabricated for the purpose; a firm brick often rubbed and laid in what the workmen term a putty-joint for the exterior, and an inferior brick for the interior, substance of the wall; but, as these did not correspond in thickness, the exterior and interior surface of the wall would not be otherwise connected together than by an outside heading-brick, here and there continued of its whole length; but, as the work does not admit of this at all times, from the want of agreement in the exterior and interior courses, these headers can be introduced only where such a correspondence takes place, which, sometimes, may not occur for a considerable space.

Walls of this kind consist of two faces of four-inch work, with very little to connect them together, and what is still worse the interior face often consists of bad brick, little better than rubbish. The practice of Flemish Bond has, notwithstanding, continued from the time of William and Mary, when it was introduced, with many other Dutch fashions, and our workmen are so infatuated with it, that there is now scarcely an instance of the old English Bond to be seen.

The frequent splitting of walls into two thicknesses has been attributed to the Flemish Bond alone, and various methods have been adopted for its prevention. Some have laid laths or slips of hoop-iron, occasionally, in the horizontal joints between the two courses; others have laid diagonal courses of bricks at certain heights from each other; but the effect of the last method is questionable, as, in the diagonal course, by their not being continued to the outside, the bricks are much broken where the strength is required.

Other methods of uniting complete Bond with Flemish facings have been described, but they have been found equally unsuccessful. In *figures* 2 and 4, (*Plate* LXXXV,) the interior bricks are represented as disposed with intention to unite these two particulars; the Flemish facings being on one side of the wall only; but this, at least, falls short of the strength obtained by English Bond. Another evil attending this disposition of the bricks is, the difficulty of its execution, as the adjustment of the bricks in one course must depend on the course beneath, which must be seen or recollected by the workman; the first is difficult from the joints of the under-course being covered with mortar, to bed the bricks of the succeeding course;

and, for the workman to carry in his mind the arrangement of the preceding course can hardly be expected from him; yet, unless it be attended to, the joints will be frequently brought to correspond, dividing the wall into several thicknesses, and thus rendering it subject to splitting, or separation. But, in the English Bond, the outside of the last course points out how the next is to be laid, so that the workman cannot mistake.

The outer appearance is all that can be urged in favour of Flemish Bond, and many are of opinion that, were the English mode executed with the same attention and neatness that is bestowed on the Flemish, it would be considered as equally handsome; and its adoption, in preference, has been strenuously recommended.

In forming English Bond, the following rules are to be observed:

1st, Each course is to be formed of headers and stretchers alternately.

2d, Every brick in the same course must be laid in the same direction: but, in no instance, is a brick to be placed with its whole length along the side of another, so that their extremities may coincide two and two; but to be so situated that the end of one may reach to the middle of the others which lie contiguous to it, excepting the outside of the stretching-course, where three-quarter bricks necessarily occur at the ends, to prevent a continued upright-joint in the face-work.

3d, A wall, which crosses at a right-angle with another, will have all the bricks of the same level course in the same parallel direction, which completely bonds the angles, as shown by *figures* 1, 3, and 6.

265. The GREAT PRINCIPLE in the PRACTICE of BRICK-WORK lies in the proclivity or certain motion of absolute gravity, caused by a quantity or multiplicity of substance being added or fixed in resistible matter, and which, therefore, naturally tends downwards, according to the weight and power impressed. In bricklaying, this proclivity, chiefly by the yielding mixture of the matter of which mortar is composed, and cannot be exactly calculated, because the weight of a brick, or any other substance, laid in mortar, will naturally decline according to its substance or quality; particular care should, therefore, be taken, that the material be of one regular and equal quality all through the building; and, likewise, that the same force should be used to one brick as another; that is to say, the stroke of the trowel: a thing or point in practice of much more consequence than is generally imagined; for, if a brick be actuated by a blow, this will be a much greater pressure upon it than the weight of twenty bricks. It is, also, especially to be remarked, that the many bad effects arising from mortar not being of a proper quality should make masters very cautious in the preparation of it, as well as the certain quantity of materials of which it is composed, so that the whole structure may be of equal density, as nearly as can be effected.

Here we may notice a particular which often causes a bulging in large flank-walls, especially when they are not properly set off on both sides; that is, the irregular method of laying bricks too high on the front edge: this, and building the walls too high on one side, without continuing

the other, often causes the defects. Notwithstanding, of the two evils, this is the least; and bricks should incline rather to the middle of the wall, that one half of the wall may act as a shore to the other. But even this method, carried too far, will be more injurious than beneficial, because the full width of the wall, in this case, does not take its absolute weight, and the gravity is removed from its first line of direction, which, in all walls, should be perpendicular and united; and it is farther to be considered that, as the walls will have a superincumbent weight to bear, adequate to their full strength, a disjunctive digression is made from the right line of direction; the conjunctive strength becomes divided; and, instead of a whole or united support from the wall, its strength is separated in the middle, and takes two lateral bearings of gravity; each insufficient for the purpose; therefore, like a man overloaded either upon his head or shoulders, naturally bends and stoops to the force impressed; in which mutable state the grievances above noticed usually occur.

266. Another great defect is frequently seen in the fronts of houses, in some of the principal ornaments of Brick-work, as, arches over windows, &c., and which is too often caused by a want of experience in rubbing the bricks; which is the most difficult part of the branch, and ought to be very well considered: the faults alluded to, are the bulging or convexity in which the faces of arches are often found, after the houses are finished, and sometimes loose in the key or centre bond. The first of these defects, which appears to be caused by too much weight, is, in reality, no more than a fault in the practice of rubbing the bricks too much off on the insides; for it should be a standing maxim (if you expect them to appear straight under their proper weight) to make them the exact gauge on the inside, that they bear upon the front edges; by which means their geometrical bearings are united, and all tend to one centre of gravity.

The latter observation, of camber arches not being skewed enough, is an egregious fault; because it takes greatly from the beauty of the arch, as well as its significancy. The proper method of skewing all camber arches should be one-third of their height. For instance, if an arch is nine inches high, it should skew three inches; one of twelve inches, four; one of fifteen inches, five; and so of all the numbers between those. Observe, in dividing the arch, that the quantity consists of an odd number: by so doing, you will have proper bond; and the key-bond in the middle of the arches; in which state it must always be, both for strength and beauty. Likewise observe, that arches are all drawn from one centre; the real point of camber arches is got from the above proportion. First, divide the height of the arch in three parts; one is the dimensions for the skewing; a line drawn from that through the point at the bottom, to the perpendicular of the middle arch, gives the centre to which all the rest must be drawn.

CHAPTER II.

ON THE CONSTRUCTION OF WALLS.

267. FOUNDATIONS.—If a projected building is to have cellars, or under-ground kitchens, there will commonly be found a sufficient bottom, without any extra process, for a good solid foundation. When this is not the case, the remedies are to dig deeper, or to drive in large stones with the rammer, or by laying in thick pieces of oak, crossing the direction of the wall, and planks of the same timber, wider than the intended wall, and running in the same direction with it. The last are to be spiked firmly to the cross-pieces, to prevent their sliding, the ground having been previously well rammed under them.

The mode of ascertaining if the ground be solid is by the rammer; if, by striking the ground with this tool, it shake, it must be pierced with a borer, such as is used by well-diggers; and, having found how deep the firm ground is below the surface, you must proceed to remove the loose or soft part, taking care to leave it in the form of steps, if it be tapering, that the stones may have a solid bearing, and not be subject to slide, which would be likely to happen if the ground were dug in the form of an inclined plane.

If the ground prove variable, and be hard and soft at different places, the best way is to turn inverted arches from one hard bearing to another, by bringing up the piers, which carry the principal weight of the building, to the intended height and thickness, and then turning the arches, as shown in *figure* 18, (*Plate* XXIX, *e*.) In this case, it is clear that the piers cannot sink without carrying the arches, and consequently the ground on which they lie, with them. This practice is excellent, and has been very successful in such cases, and should, therefore, be general, wherever required.

When the hard ground is to be found under apertures only, build your piers on these places, and turn arches from one to the other. In the construction of the arches, some attention must be paid to the breadth of the insisting pier, whether it will cover the arch or not; for, suppose the middle of the piers to rest over the middle of the summit of the arches, then the narrower the piers, the more curvature the supporting arch ought to have at the apex. When arches of suspension are used, the intrados ought to be clear, so that the arch may have the full effect: but, as already noticed, it will also be requisite here that the ground on which the piers are erected be uniformly hard; for it is better that it should be uniform, though not so hard as might be wished, than to have it unequally so: because, in the first case, the piers would descend uniformly, and the building remain uninjured; but, in the second, a vertical fracture would take place, and endanger the whole structure.

268. WALLS, &c.—The foundation being properly prepared, the choice of materials is to be considered. In places much exposed to the weather, the hardest and best bricks must be used, and the softer reserved for in-door work, or for situations less exposed. In slaking lime, use as much water only as will reduce it to a powder, and only about a bushel of lime at a time, covering it over with sand, in order to prevent the gas from escaping. This is a better mode than slaking the whole at one time, there being less surface exposed to the air: for, in thus suffering the gas to escape, we lose that virtue of the lime which constitutes its hardening quality.

Before the mortar is used, it should be beaten three or four times over, so as to incorporate the lime and sand, and to reduce all knobs or knots of lime that may have passed the sieve. This very much improves the smoothness of the lime, and, by admitting air into its pores, will make the mortar stronger: as little water is to be used in this process as possible. Whenever mortar is suffered to stand any time before used, it should be beaten again, so as to give it tenacity, and prevent labour to the bricklayer. In dry hot summer-weather use your mortar soft; in winter, rather stiff.

In laying bricks in dry weather, by wetting the bricks, or by causing water to be thrown over them before they are used, will greatly add to the strength and durability of the work. Few workmen are sufficiently aware of the advantage of wetting bricks before they are used; but experience has shown that works in which this practice has been followed have been much more durable than others wherein it has been neglected. It is particularly serviceable where work is carried up thin, and in putting in grates, furnaces, &c.

In the winter season, as soon as frosty weather sets in, cover your wall with straw or boards; the first is best, if well secured; as it protects the top of the wall, in some measure, from frost, which is very prejudicial, particularly when it succeeds much rain; for the rain penetrates to the heart of the wall, and the frost, by converting the water into ice, expands it, and causes the mortar to assume a short and crumbly nature, and altogether destroys its tenacity, before it has acquired a sufficient hardness to resist it.

In working up a wall, it is proper not to work more than four or five feet at a time; for, as all walls shrink immediately after building, the part which is first brought up will remain comparatively stationary; and, when the adjoining part is raised to the same height, a shrinking in the latter will take place in a much greater degree than in the former, which will separate from the latter, causing a crack, which will become more evident as the work proceeds. In carrying up any particular part, each side should be sloped off, to receive the bond of the adjoining work on the right and left. Nothing but absolute necessity can justify carrying the work higher, in any particular part, than one scaffold; for, wherever it is so done, the workman should be answerable for all the evil that may arise from it.

269. The distinctions of *Bond* have already been shown, and we shall now detail them more particularly; again referring to *Plate* XXIX, *e*, in which the arrangement of bricks, in depths of different thicknesses, so to form *English Bond*, is shown in *figures* 1, 3, 6, and 7.

The bond of a wall of nine inches is represented by *fig.* 1. In order to prevent two upright or vertical joints from running over each other, at the end of the first stretcher from the corner, place the return corner-stretcher, which is a header, in the face of the wall in which the stretcher is in below, and occupies half its length; a quarter-brick is placed on its side, forming together 6¾ inches, and leave a lap of 2¼ inches for the next header, which lies with its middle upon the middle of the header below, and forms a continuation of the bond. The three-quarter brick, or brick-bat, is called a *closer*.

Another way of effecting this is, by laying a three-quarter bat at the corner of the stretching-course; for, when the corner-header comes to be laid over it, a lap of 2¼ inches will be left at the end of the stretchers below for the next header; which, when laid, its middle will come over the joint below the stretcher, and in this manner form the bond.

In a fourteen-inch or brick-and-half wall, (*fig.* 3,) the stretching-course upon one side, is so laid that the middle of the breadth of the bricks, upon the opposite side, falls alternately upon the middle of the stretchers and upon the joints between the stretchers.

In a two-brick wall, (*fig.* 6,) every alternate header, in the heading-course, is only half a brick thick on both sides, which breaks the joints in the core of the wall.

In a two-brick and a half wall, (*fig.* 7,) the bricks are laid as shown in *figure* 6.

Flemish Bond, for a nine-inch wall, is represented in *figure* 2, wherein two stretchers lie between two headers, the length of the headers and the breadth of the stretchers extending the whole thickness of the wall.

In brick-and-half Flemish bond, (*fig.* 4,) one side being laid as in *figure* 2, and the opposite side, with a half-header, opposite to the middle of the stretcher, and the middle of the stretcher opposite the middle of the end of the header.

Figure 5 exhibits another arrangement of Flemish Bond, wherein the bricks are disposed alike on both sides of the wall, the tail of the headers being placed contiguous to each other, so as to form square spaces in the core of the wall for half-bricks.

The *Face of an upright-wall*, English Bond, is represented by *figure* 19, and that of Flemish Bond, by *figure* 20.

270. Brick-nogging is a mode of constructing a wall with a row of posts or quarters, disposed at from eighteen inches to three feet apart, with brick-work filling up the intervals. In this mode the wall is, generally, either of the thickness or breadth of a brick, and the wood-work projects on both sides with the faces of the brick-work about three-quarters of an inch, in order to make a proper allowance for the irregularity of the splitting of the lath. Thin pieces of timber, called *nogging-pieces*, laid horizotally from post to post, are so disposed as to form brick-work between every two posts or quarters, into several compartments in the height of the story; each piece being inserted between two courses of brick, with its edges flush with the wall.

271. Cornices.—In respect of brick cornices, many pleasing combinations may be made; thus, *fig.* 21 shows the rudiments of a Doric entablature; and *fig.* 22, that of a dentil cornice.

272. As the building of high brick-walls in situations where the ground is infirm, or where sound ground is covered with deposited soil, so as to be executed at the cheapest rate with superior strength and durability, is of the greatest importance to those who may have occasion to erect such walls; we shall, therefore, make no apology in laying before our readers the following description, though particularly applicable to the surrounding walls of Coldbath-Fields Prison, including the Female Penitentiary, may be generally applied to all others under the like circumstances.

Fig. 1, *Plate* XXIX, exhibits a general plan of Coldbath-Fields Prison, ABCD is the surrounding wall of the old prison, *e*, *f*, *g*, *h*, *i*, *k*, *l*, *m*, B, the surrounding wall of the intended Penitentiary, which was built upon ground over which was deposited a soil, varying from twenty to six feet in depth. The small circles exhibit the plans of the piers upon which circular buttresses or counterforts were erected to strengthen the wall, at a distance from each other, varying from 28 to 36 feet, according to circumstances. *Fig.* 2, a portion of the new and old walls, *a*, *b*, *c*, *d*, being the elevation of the new part, exhibiting the foundation and the superincumbent wall. This portion of the new wall exhibits six piers. Over every second pier a circular buttress, projecting from both faces of the wall, was erected; the part of the elevation, *fig.* 2, exhibits three of these buttresses. *g*, *h*, *c*, *i*, (*fig.* 2,) exhibits a portion of the prison-wall with one of the buttresses. The plans of both parts of this elevation is exhibited at *fig.* 3; the plan of the buttresses of the old wall being rectangular, whereas that of the new wall is circular. *Fig.* 4, exhibits the elevation to a large scale of a portion of the new wall, containing one buttress and a part of another, with one aperture and part of another, in order to show the brick-work in the foundation, and superincumbent part of the wall, to the greatest advantage, as also the use of the invert and insistant arches. The plan of this is shown below, at *fig.* 5.

The following attestation, delivered to the president and members of the institution of civil engineers, by a gentleman who was connected with the building of the walls here referred to, will show the great advantage of such a mode of construction.

273. "A piled and sleepered foundation (unless it had been of oak) must soon have perished, and the expence of such a foundation would have been greater than the whole of the wall and coping taken together. The advantage of invert and insistant arches, in a work of this kind, is a more efficient footing than stone landings, and the latter gives a longitudinal connection to the work, which is particularly desirable to consolidate it in that direction.

"The circular piers give the greatest lateral stability with the least quantity of work, presenting a convenient form towards a public way, and secure from escapes on the prison-side by avoiding angles. This disadvantage, of piers placed on one side, arises from the equilibrium being destroyed, in all cases that have been examined of this kind. The wall inclines towards the side on which the piers are placed. By this method, shown on the drawing, we are enabled

to lay foundations at considerable depths, without adding much additional weight, and thereby a permanent foundation by using only imperishable materials. Another advantage obtained by this method arose from having occasion to raise the ground in some places fourteen feet; with these large apertures the ground settles uniformly, without pressing unequally against either side of the wall, and thereby preserving its vertical position.

"The motives which directed this plan were two: viz. the failure of piles and sleepers in some foundations that had been taken up, about three years since, within the prison-walls; and secondly, economy: for, if pile and sleeper foundations had been adopted, the expense would have been increased at least one-third. It would be superfluous to go into the detail of execution; suffice it to say, that, with good materials and workmanship, a work upon this principle would possess a durability equal to the most expensive mode of execution."

CHAPTER III.

ON THE CONSTRUCTION OF ARCHES FOR CYLINDRICAL VAULTS.

274. An Arch, in brick-work, is a mass of bricks so arranged, that, in the profile, or right section, the under line or intrados is generally a curve, which is always concave towards the aperture, and the joints between the bricks radiate towards a centre, in such a manner that each joint ought always to be perpendicular to the curve. In order to form a rectangular aperture, the under-line, which terminates the head of the right section, is a straight line. In such a case, the joints must still radiate to a centre in the middle of the breadth of the aperture; but these joints cannot be perpendicular to the soffit, as was the case when the intrados or soffit was a curved surface. An arch does not always imply a mass of bricks or stones supported at the extremities, and terminating upon a concave surface over a hollow. The principle of a brick or stone arch arises from the radiating directions of the joints, which, in fact, divides the arch or vault into separate bricks, in the form of the frustum of a wedge, of which the lesser ends form the intrados of the arch. It is easy to see that none of these bricks, thus separated by the radiating joints, can descend, for the aperture through which any brick has to pass being narrower at the bottom than at the top, will not admit of the wide end of the wedge to pass through it, nor even to descend to any distance, however small. Hence a mass of bricks or stones, connected by radiating surfaces, will support each other, even though the intrados may be a plane surface; what is called the curve of equilibrium being within the solid mass. Arches are therefore of several kinds, when the profiles are circular, as *straight arches*, *semi-circular arches*, and *segmental arches;* which are also called *scheme arches*.

The springings of a semi-circular arch are in a plane parallel to the horizon; the springings of a scheme arch are in two planes, each being at right-angles to the tangent plane to the intrados at the commencement of the curve.

The springings which are neither parallel nor perpendicular to the horizon, are called, in the technical language of the bricklayer, skew-backs. Straight arches must have skew-backs, as well as scheme-arches.

275. *Fig.* 13, exhibits the right section or profile of an arch for the head of an aperture, which forms the intrados of a straight arch; the manner in which these joints are drawn will be shown in the following description (see *fig.* 17). Upon the width, AB, of the aperture as a base, describe an equilateral triangle, and from the vertex, C, with a radius equal to the thickness of a brick, describe a small circle. Draw DE, the extrados of the arch, at such a distance from the intrados as is equal to the breadth of the arch, which, in this example, is equal to the height of four courses of bricks in the face of the wall, and draw the skew-backs, AB and DE, one at each extremity of the arch. Draw a line parallel to one of the skew-backs, (which ought to be a tangent to the small circle,) cutting the intrados in F, and draw the straight line CF. Find the point G in the same manner, and draw GC, and so on to the middle, when the operation will be complete.

Fig. 14, is the profile of the head of an aperture with a part of each jamb, the head being a scheme-arch. It is contained between two concentric circles and the springing-lines, which are portions of the radii of these circles. *Fig.* 15, is a semi-circular arch.

276. *Fig.* 16, a semi-elliptic arch, struck from two centres, A and B, having the longer axis in a position parallel to the horizon. The method of describing elliptic arches is as follows (see *Plate* XXIX. *g.*) Let AB be the span of the arch, and CD its height, from the middle of AB, and perpendicular thereto. Draw Ax and Dx respectively parallel to CD and CA, and divide Ax and AC each into three equal parts, by the two intermediate points, 1, 2. Make Cz equal to CD, and from the points 1, 2, in Ax, draw straight lines to the point D, intersecting straight lines drawn from the points 1, 2, in AC, in the points y and n. Make the angle Dnh equal to the angle nDC, and prolong DC to meet nh in h. Join yn, or suppose yn to be joined, and bisect yn by a perpendicular meeting nh in i. Join yi, intersecting AB in k, and let nh intersect AB in l. In CB, make Cr equal to Cl, and from h, through r, draw hu. In hr, make hq equal to hi, and in CB, make Cs equal to Ck. Join qs, and prolong qs to t. From the centre h, with the radius hD, describe the arc nu, and from the centres i and q, describe the arcs ny and ut, and from the centres k and s describe the arcs yA and tB. Then will AynuDutB be the intrados of the arch. Prolong the lines iy and in, qu and qt, as also CA, CB, to E, o, p, w, r, F, and make DG equal to the breadth of the arch; then, by the same centres, h, i, q, k, s, describe the extrados EopGwvF, which will complete the right section of the arch. The joints of the bricks are drawn through the same centres, observing that the extrados must be divided into parts, each equal to the thickness of a brick.

277. Gothic Arches.--Let AG be the span of the arch, (see *figures* 2 and 3,*) DC the perpendicular height from D, the middle of the spanning line AG, and let CB be a tangent to the arch at the summit C, and AB perpendicular to AG, a tangent at the springing point A.

278. *To describe the Gothic Arch, fig. 2, by finding any number of points in the curve.*—Prolong CD to *f*, and in D*f* make DE equal to the difference between the two perpendiculars, AB and DC. Join AE, and divide AE and AB each into the same number of equal parts, as in this example each of these lines is divided into six equal parts. Through the points, 1, 2, 3, &c., in AB, draw straight lines to the point C, and from the point *f*, through the points 1, 2, 3, &c., in AE, draw right lines, to intersect the former right lines, (concurring in C,) in the points *a*, *b*, *c*, &c. Through these points draw the curve A *a b c d e* C, and thus we have constructed one half of the section of the intrados of the arch. In the same manner, the other half of the section of the intrados may be constructed. The extrados lines, HJ and IJ, are found by drawing them at an equal distance from the intrados lines AC and GC.

279. *To describe a Gothic Arch by centres.*—In *fig.* 3, draw C *m* perpendicular to CB, and in the span AG, make A *k* equal to AB. In C *m*, make C *l* equal to A *k* or AB, and join *k l*. Bisect *k l* by a perpendicular, meeting C *m* in *m*, and join *m k*. Prolong *m k* to *n*. From the point *m*, as a centre, with the distance *m* C, as radius, describe the arc C *n*, and from the centre *k*, with the distance *k n*, describe the arc *n* A. Then A *n* C will be half of the curve of the section of the intrados. Prolong AG, the spanning from each extremity, to H and I, and prolong *k n* to *o*. Make AH equal to the breadth of the course which forms the head of the arch; then again from the centre *k*, with the radius *k* H, describe the arc H *o*, and from the centre *m*, with the radius *m o*, describe the arc *o* J, meeting the summit in the point J. In the same manner may be found the extrados and intrados of the other half of the right section of the arch. But the centres may be found more readily by the following construction, by observing that the centres must be in a symmetrical position on each side of the right line CD, which divides the right section into two symmetrical parts. Make D *p* equal to D *k*, and prolong CD to *q*. Draw *m r* parallel to the spanning line GA, intersecting CD prolonged in *q*, and make *q r* equal to *q m*. Join *r p*, and prolong *r p* to *s*. Join *r* C; then, from the centre *r*, with the distance *r* C, describe the arc C *s*, and from the centre *p*, with the radius *p s*, describe the arc *s* G. Again, making GI equal to AH, from the centre *p*, with the radius *p* I, describe the arc I *t*, meeting *p s* prolonged in the point *t*; and from the centre *r*, with the radius *r t*, describe the arc *t* J; and thus we have described the whole of the right section of the arch.

280. One observation which the bricklayer must attend to, in dividing the section of his arch into bricks, by drawing the joints, is, that he must divide the extrados, or outside curve, into equal parts, and not the inside curve, as this would occasion the bricks to be of a greater size than they are made.

* These constructions, exhibited in *figures* 2 and 3, are the invention of Mr. Peter Nicholson, to whom the art of building is greatly indebted; and it is important to remark, in the construction, *fig.* 2, that when AB is greater than the half of DC, the curve AC is elliptic; when equal to the half of BC, it is parabolic; and when less, it is of the hyperbolic kind.

281. In order to show the construction of brick arches in the Gothic style of architecture, we have selected two examples of windows from the church now erecting at Tottenham, in the neighbourhood of the city of London. The elevations and plans, with other details, are exhibited in *Plates* XXIX. *h*, and XXIX. *i*.

Fig. 1, *Plate* XXIX. *h*, is the elevation of the west-end window, having a triple aperture, each of which is arched with two concave curves meeting in point at the summit, and thereby forming pointed or Gothic arches. Here it may be observed, that the level of the springings of the two side arches is much below the level of the springing of the middle arch. These three arches are hooded with labels, of which the mouldings over the arch of the middle aperture descends upon each side vertically, in order to meet those of each of the side arches. No. 1, exhibits a section or profile of the label-mouldings to a scale sufficiently large that the smallest members may be rendered distinct. No. 2, exhibits a section of the sill, consisting of two faces, terminating below with a fillet, hollow, and bead, which forms a throat or drip for discharging the water from the surface of the walls, and thus preventing the decay of the brickwork.

Fig. 2, Elevation of one of the side-doors, where, instead of vertical joints at the apex of the arch, as in the windows in the other plate, a key-brick is introduced. The label-moulding, or hood, has its parts straight, which are joined to each other at right-angles; the upper part is level, and each of the side-parts descend in a vertical position.

Fig. 1, *plate* XXIX. *i*, exhibits the elevation of a double-lighted window, which, except the want of the label, is formed in every respect in the same manner as the triple-lighted window, *plate* XXIX. *h*. It will be proper here to observe, that, in the constructions of the heads of these windows, instead of cutting the bricks which form the arches from rectangular bricks, they were previously prepared to the arched and tapering forms by means of moulds before they were burned; and though the joints of the bricks were always marked in the elevation, yet, in order to preserve the beauty and regularity of the bond, several lines are exhibited, which are only lines cut across the edge, in order to give the appearance of joints where they would naturally be expected, in order to complete the continuity. No. 1 and No. 2, are horizontal sections of the window, exhibiting the manner of laying the alternate courses of brick in the piers and jambs. The capitals in the two horizontal sections, corresponding to the small letters in the elevation, exhibit the sides and edges of the brick in the ascending courses of the work. *Fig.* 2, exhibits the brick of which the upper face is shown at D, No. 2; *fig.* 3, exhibits the brick of which the upper face is shown at C, No. 1; and *fig.* 4, exhibits the brick of which the upper face is shown at A, No. 2.

CHAPTER IV.

ON THE CONSTRUCTION OF VAULTS FOR WAREHOUSES AND CELLARS.

Introductory Principles and Observations.

282. A simple vault is a mass of bricks, or stones, forming a concavity over a hollow, and extending between two opposite walls, which are generally parallel, or otherwise supported upon a circular wall. The concave surface towards the hollow is called the intrados, which is generally a portion of a cylindrical surface, or that of a spherical surface, never greater than the half of the solid. The surface from which the vault rises is called its springing. If the vault be the surface of a semi-cylinder, or that of a hemisphere, the two springings are both contained in one plane; if the right section of the intrados of the vault be a segment of a circle, the springings are generally inclined planes, as they ought to be, and if the intrados be a portion of a hemispheric concave surface, the springing surfaces will be in the surface of a right cone, that is, the springing surface will be the surface of a conic zone. In lime and brick kilns, vaults are formed of conic surfaces, having their axes vertical. The wooden dome of St. Paul's Cathedral, London, is supported upon a conical vault of brick-work, having the axis of the conic surface in a vertical position. Conic surfaces, of which their axes are in vertical positions, are very seldom used in private buildings, except in walls over the apertures of doors and windows where the jambs are splayed, in order to admit a greater quantity of light into the interior of the building. All vaults of which the axis of the intrados has a horizontal position are called horizontal vaults; and such as have their intrados portions of the surfaces of cones and cylinders with their axes horizontal, are also called horizontal vaults.

283. A groin-vault is that of which the intrados is formed by the intersections of two or more cylindric surfaces, of which their axes are in a horizontal position, intersecting each other in one common point, so that no part of the surface of one cylinder may be contained between the concavity of another. In cylindrical groined vaults, the convex surface of either cylinder may extend without the convex side of the other. In general, the summits of the cylindrical surfaces are right lines intersecting each other, and are in the same horizontal plane. When the sections of the cylindrical surfaces are circles, and the diameters unequal, the groined vault is that which is called by workmen a Welsh groin. When a groined vault consists of two cylindric surfaces, the axes are generally at right angles to each other, and as they terminate upon walls at right-angles to their axes, the sides are constructed upon a rectangular plan.

284. It has been long experienced and universally acknowledged, that rectangular-groined vaults are necessarily of a weak and imperfect construction, and the figure of the piers is incommodious for warehouses or other buildings. It is manifest to every one who will take the trouble to examine them, that a very great part of the substance of the bricks which constitute the ground angle is cut away, in order to form the intended surface upon each side of the line in which the two cylindrical surfaces meet each other, so that the lengths of the bricks thus forming the angle may be parallel to the axis of a cylindrical surface, and so placed alternately in each cylindrical surface; and thus the joints of the bricks will be preserved in right lines parallel to the axis. The slanting or oblique direction in which it is necessary to cut the bricks at the groin-angles render them extremely liable to be thrust out of their situations by any sudden impulse operating upon the crown of the arch, and thus instead of presenting the greatest resistance, are the most feeble that can be conceived, and were it not for the adjacent arches they would be incapable of supporting themselves. Hence, when such a construction has been loaded with stones, the superincumbent weight has been found to act chiefly in the direction of the groins, although they are least capable of resisting it. Therefore, it follows, that the stronger these parts are made, the better the whole arch will counteract the tendency to fracture. Instead of square piers, so commonly used, octagonal ones will be found much more convenient and more susceptible of admitting the necessary improvements; and since the right angles are taken away, there will be more room for goods, and for the turning of casks, without endangering the breaking of the angles. The improvements in the construction of vaults, consists in carrying a cylindrical arch, in breadth equal to the length of a brick, a brick-and-half, or two bricks, instead of the angle or groin from pier to pier, depending on the extension of the interval between the piers.

As the diagonal of a square is longer than either of its sides, the girt of the elliptic cross-ribs must be greater than the girt of the semi-circular arch; on this account, in such a construction, it is not possible to keep the joints of the brick-work of the filling-in arches upon the same level as the joints of the brick-work constituting the ribs. In order to save expense in the cutting of the bricks, and to prevent the irregularity at the junctions, it will be found necessary to cut off all communication between the cross and the filling-in arches, by making the cross-arches project from the filling-in arches at the surface where they join each other. By setting back the filling-in arches affords a most excellent opportunity of binding the work. This improvement upon groins was first suggested by Mr. George Tappen, architect.

285. Another mode of vaulting has been introduced in St. Catherine's Docks, of which the pendent parts, resting upon the piers, are solids of revolution, being concave in their vertical sections, and convex in their horizontal sections, which are the arcs of circles. This form possesses some advantages, as the courses may be so arranged that their joints will be in conic surfaces. The principle is the same as was applied in the stone roof of the Chapel of King Henry VII., Westminster, and at the Chapel of King's College, Cambridge, and will show a

very considerable variation in the mode of execution. If the axes of the piers are raised from the angles of a square, and if the vertical section through the axis of the diagonal piers be a given semi-circle, the vertical sections of the side arches will be of the Gothic form; and if the vertical sections of the side arches be given semi-circles, a quadrilateral space will be formed in the centre of the groined severy,* and will have its four sides contained in a plane, which will be a tangent to the curved surface of revolution. It is obvious that the exterior form of the surface of each pendent of the groined severy is that of the exterior form of a trumpet, which is a surface of revolution. When the sides are semi-circles, and all the four pendents complete, the curved surface of the intrados may be made to touch a plane surface, which will be a tangent at every point to the surface of revolution; but, as the space enclosed by the sides of the quadrilateral must be filled in before the arch is completed, it is evident that the mass included will not partake of the principle of an arch, because the joints are all in the surfaces of prisms, and not in radiating surfaces, as is the case with the four pendents rising from the piers: this defect may be rectified by making the side arches pointed, instead of one continued curve from pier to pier. For by this means, the plane which contains the quadrilateral will not touch the points of the curved surface of the pendent parts; but will form an aperture of less dimensions at the bottom than at the top, and consequently will allow a sufficient spread for the radiations of the joints. It is obvious that the joints of the pendents are partly in conical surfaces, and partly in vertical planes, and that the conical surfaces intersect the intrados in the arcs of circles which have their centres in the axes of the four piers; that is, in the axis of each surface of revolution forming the intrados of each pendent over each of the piers.

286. Another mode of vaulting with brick, which has been found to answer the purpose extremely well, will easily be understood from the following description:—Imagine a quadrant of an ellipse comprised between two semi-axes and the portion of the curve between them to revolve round the semi-axis minor, the surface of revolution will be the half of a probate spheroid, terminated by a circle generated by the semi-axis major. The spheroidal surface generated by the quadrantal arc of the ellipse is well adapted for a vault suspended by a circular wall, or a wall upon a circular plan; but, in order to vault over an area raised from a square plan, let us suppose that we have such a hemispheroid, and that the diameter of its great circle is equal to the diagonal of the square plan. Upon the plane of the great circle of this spheroid, suppose two diameters are to be drawn at right-angles to each other, and the extremities of these diameters to be joined by straight lines, so as to form a square inscribed in the circumference. Let this hemispheroid be cut by four planes, each passing along one of the sides of the square perpendicularly to the plane of the circle, the portion of the hemispheroidal surface will be the exact centre for such a vault, and, consequently, the concave surface, coinciding with

* SAVERY, or severy, is the proper name for every compartment of vaulting. The word may be seen in turning over the pages of our ancient records, where the description of the ceilings of old buildings are registered. It is not, however, to be found in Johnson's Dictionary, not even in the late editions which contain the numerous insertions of the Rev. H. J. Todd. See Bretton's Architectural Antiquities of GREAT BRITAIN.

the centre, will be the surface forming the intrados of the vault adapted to the square plan of the dimensions here assigned.

If it were required to adapt such a spheroidal surface to an oblong plan, let the hemispheroid be so formed that the diameter of its great circle may be equal to one of the diagonals of the oblong plan, and the semi-axis of rotation equal to the intended height of the vault. In this case, let one of the diagonals be drawn on the plane of the great circle, and this diagonal will divide the great circle into two semicircles. From one extremity of the diameter thus drawn, with a radius equal to the one of the sides of the oblong plan, cut the one semi-circumference, and from the same point, with a radius equal to the adjacent side of the oblong plan, cut the other semi-circumference. Join each point of section to each extremity of the diameter, and the figure, thus formed, will be an oblong of the same dimensions as the plan of the vault; let the four semi-segments of the hemispheroid be lopped off, by cutting planes, passing each along each side of the inscribed rectangle perpendicularly to the plane of the great circle, and the remaining portion of the hemispheroid will be the form of the centre for building a vault of the figure here required. It will be of use to inform the carpenter who has to construct the centre, and the bricklayer who has to form his vault upon that centre, that as all parallel sections of a spheroid are similar ellipses, the semi-ellipses which terminate upon each wall will be similar to the generating ellipses; that is to say, the span of the vault between the two diagonals is to its height, as the side of the rectangle, which is the axis-major of the elliptic section terminating upon that side, is to the height of this section. The bricklayer has now all the principles which are necessary to construct such a vault.

With respect to the manner of building, the courses of bricks may be very conveniently disposed in concentric circles receding from the crown of the vault as their centre; hence, by this means, all the joints will form the surfaces of as many cones as there are courses. This mode of vaulting has been adopted under the New Hall in Christ's Hospital, London, and is considered as a very great novelty, both by architects and ingenious workmen; the manner which the workman or architect has chosen to lay the courses is not that here described, nor would it be easy to give such ideas to the bricklayer that he may dispose of his courses in the same manner: it will, however, be sufficient to say, that the courses run in directions parallel to the diagonals, and meet each other in vertical planes parallel to the sides of the rectangle.

The Principles of Brick-Vaulting, as in Common Groins.

287. *Plate* XXIX. *k*, *fig.* 1, exhibits the plan of a common rectangular groin, the shadowed parts being the horizontal sections of the piers, and the diagonal lines the plans of the groins or angles; *fig.* 2, exhibits an elevation or right section through the principal arch of the groined severy; and *fig.* 3, an elevation or right section of two of the transcept arches. *Fig.* 4, exhibits the intrados of one of the transcept arches extended upon a plane; and *fig.* 5, exhibits the intrados of the two opposite parts of one of the principal arches.

In order to trace the forms of the ribs of a common cylindrical groin upon a rectangular plan, let AB, *fig.* 1, be the base of one of the transcept arches, at right-angles to the axis of the opening, and let A *b c*...B be the section of the intrados of that arch, being a semi-circle, of which the diameter AB is the base of the arch. In the section of the intrados of the semi-circular arc of the transcept, which is the given section, take any number of points, *a, b, c,* &c., and from the points *a, b, c,* &c., draw the straight lines *b h, c i, d k,* &c., to meet the base AB. From the points *h, i, k,* &c., in the base line, AB, of the given rib, draw straight lines *h h'*, *i i'*, *k k'*, &c., parallel to the axis of the cylindrical surfaces of the transcept arches that is perpendicular to AB, and from the points *h', i', k',* &c., in the plan, CD, of the diagonal rib, draw the straight lines *h' b'*, *i' c'*, *k' d'*, &c., perpendicular to CD, as ordinates. Make the ordinates, *h' b'*, *i' c'*, *k' d'*, &c., successively equal to the ordinates *h b, i c, k d,* &c., of the semi-circular arc of the right section, and from the point C, and through the points *b', c', d',* &c., draw the curve C *b' c' d'*...*g'*, and C...*d'*...*g'* is the curve of the groin line over CD. Let G *n''* be half the base of the rib over the principal opening; then, in order to draw the section of the intrados of the half-rib over G *n''*, draw the straight lines, *h' h''*, *i' i''*, *k' k''*, &c., parallel to the axis of the principal vault, and from the points *h''*, *i''*, *k''*, &c., in the half base C *n''*, draw the straight lines *h'' b''*, *i'' c''*, *k'' d''*, &c., perpendicular to G *n''*, as indefinite ordinates. Make *h'' b''*, *i'' c''*, *k'' d''*, &c., respectively equal to *h b, i c, k d,* &c. of the semi-circular arch, and from the point G, and through the points *b'' c'' d''*...*g''*, draw the curve G . *d''*...*g''*, which will be the section of the intrados of the principal arch.

The Principles of Brick-Vaulting, as in the London-Docks.

288. *Plate* XXIX, *l.* contains the plans, sections, and elevations of the groining of the London-Docks. *Fig.* 1, No. 1, a plan exhibiting four of the groined severies, the octagonal sections of the pillars which support the vaulting, and the plans of the intersections of the surfaces, which altogether form the intrados. Here the intrados is formed by four cylindric surfaces; that is to say, by cylindrical surfaces in four directions, one being in each direction. The axes of two of the cylindrical surfaces are parallel to the sides of the square which forms the plan of each severy, and the axes of the other two in the planes of the diagonals; the four axes being in a horizontal position, and intersecting each other at equal angles. *Fig.* 1, No. 2, exhibits a section through two of the severies, showing the pillars and arches, and the method of constructing the foundation. This section is taken parallel to one of the sides of a severy, and exhibits the dimensions of each of the arches, the piling under the foundation, and the offsets upon which each of the pillars stand.

The arches parallel to the sides are equal to each other, and the arches in the eight diagonals are also equal to each other; but the arches upon the sides differ from the diagonals. The cylindrical surfaces, which extend from pier to pier, have their plans narrower towards the

piers than at the crown, in which they form a square. The method of tracing these groins will be very easy, since the intersections of the cylindrical surfaces are all in vertical planes passing through their plans. *Fig.* 2, exhibits a section of one of the arches, the various lengths of the radius of curvature for drawing the sections of the arches, as also the extent of the portion of each curve, and the heights of the courses which form the offsets. *Fig.* 3, a plan of the plinth, the pillar, and the stone below the plinth. *Fig.* 4, a plan of the springing-stone, and its various lines of intersection, in planes parallel to the horizon. As the scales are here affixed to each of the four figures, the reader cannot be at any loss to find the dimensions of any required part.

The Principles of Brick-Vaulting, as in St. Catherine's Docks.

289. Example 1.—*Plate* XXIX. *m*, contains the plans and sections of the vaulting belonging to St. Catherine's Docks. *Fig.* 1, No. 1, exhibits the plans of four of the severies; *fig.* 1, No. 2, shows the elevations of the arches parallel to the sides of the narrow openings; and *fig.* 3, the elevation of the arches parallel to the sides of the wide openings. We shall here suppose the curve between two diagonal piers to be given, and that the curves extending between the centres of the piers, upon the sides, are required to be found. Let CDEF, No. 1, be the plan of one of the piers; CHI the quarter of the plan of the opposite diagonal piers; KLMN the plan of half of one of the side-piers; and OPQR the plan of one half of the opposite diagonal piers. The plan of the whole pier, and the plans of the parts of the other three piers, are those which belong to a complete severy. Let the right line, $a\,b$, extend from the centres a and b of the opposite piers, and let $k\,p$, in the line $a\,b$, be the plan of the curve-line, formed by a vertical plane cutting the intrados of the vault; and because all straight lines in a plane perpendicular to the plane of projection are projected into straight lines, the plan $k\,p$ is a right line. Let $k\,l\,m\,n\,..\,o\,..\,p$, be the curve-line of the section of the intrados, of which the plan is $k\,p$, and let this curve-line be a semi-ellipse, of which the axis-major is $k\,p$, the centre y, and the semi-axis minor $y\,z$. Let the centres of the plan of the four piers be a, b, c, d; then the straight lines joining these points, to form the rectangular plan of the severy, are $a\,c$, $c\,b$, $b\,d$, and $d\,a$; and these four straight lines, which form a rectangle, may be considered as the plans of four curves, formed by the intersection of as many vertical planes and the intrados of the vaulting. Bisect $a\,d$ in the point t', and from a, with the distance $a\,t$, as radius, describe the arc $t'\,x$. From c, with the same radius, describe the arc Ux, from b describe the arc UV, and from d describe the arc t V. Join Ex and Mx, as also HV and OV. In the plans of the piers, the sides LM, DE, CF, HI, OR, and PQ, are all parallel to the longest sides of the severy; and the lines DE, CF, are equally distant from the centre a. The ares CD and EF are described from the centre a, with the same radius. The same is to be understood of the other three plans of the piers. The intrados of the vaulting between two vertical

planes, passing through or along $a\,t'$ and $a\,x$, is revolved; therefore, between these two planes, the joints between the courses of bricks in the intrados are situated in the arcs of circles.

Hence all the vertical sections of the intrados, passing through the point or centre a, will be all of the same curve between the vertical planes passing along $a\,t'$ and $a\,x$; therefore, the curve upon $a\,t'$, the half of the side-arch will be equal to the curve upon $a\,t$ in the plane of the diagonal, and the equal ordinates of each of these curves, will spring from concentric circles described from the point a; hence, without tracery, each half of the curve standing upon $k'\,p'$, and all the sections of the curves between the vertical planes passing along $a\,x$ and $a\,t'$, will be the same as the curve $k\,l\,m\,n\ldots.o$, of the rib standing upon the diagonal, $k\,p$. The curve upon the narrow side, $a\,c$, will differ from the curve in the plane of the diagonal standing upon $a\,p$, because half the base $k''\,t''$ of the curve upon $a\,c$ is less than $k\,x$, for the same reason that either of the sides of a right-angled triangle is less than the hypothenuse.

Let $q, r, s\ldots.t$, be any number of points taken in the base $k\,p$ of the curve of the intrados, in the diagonal plane, and describe the arcs $q\,u$, $r\,v$, $s\,w$, &c., meeting $a\,x$ in the points u, v, w, &c. Draw the straight line $t''\,x$ parallel to the side N G of the severy, and $t''\,x$ will bisect the breadth, and will represent the axis of the cylindric surface; therefore, draw the straight lines $u\,q''$, $v\,r''$, $w\,s''$, &c. parallel to $x\,t''$, to meet the narrow side $k''\,p''$ of the severy in the points q'', r'', s'', &c., and draw the straight lines $q''\,l''$, $r''\,m''$, $s''\,n''$, &c. Make $q''\,l''$, $r''\,m''$, $s''\,n''$, &c., each equal respectively to $q\,l$, $r\,m$, $s\,n$, &c., in the plane of the diagonal, and draw the curve $k''\,l''\,m''\,n''\ldots.o''$, which will be the half of the intrados of the section of the arch. As all these sections are symmetrical figures, that is, as one-half is the counterpart of the other, the other half will be readily found without farther instruction.

We have nothing more to remark, than that the sections of the side-arches are both pointed, and that each counterpart of the long side-arch is a portion of the arch extending from the one centre to the other of the two diagonal piers.

The method of constructing the centres will be shown in the description of the next plate, as also the construction, with revolved surfaces, when the plan is square. The figure here is a groined-vault, consisting of two different surfaces, one revolved and the other cylindric.

290. Example 2.—*Plate* XXIX. *n*, contains a plan of one of the severies of St. Catherine's Docks, with a plan of the centering for one-quarter of the severy, and the detail of the parts. This construction is more simple than that in the preceding plate, the intrados of the vaulting being entirely formed by surfaces of revolution, of which the axis is the axis of each pillar. In order that the surface of the intrados may be concave at the crown throughout, it will be necessary to have the vertical section through the diagonal of the severy given, as in *Plate* XXIX. *m*; and as there are no groined angles, all the sections radiating from the pillar to the summit, will be parts of the diagonal section, and the intersections of the intrados upon the sides of the vaults will, therefore, be Gothic arches. The curves upon each of the two narrow sides will be more pointed than each of the two curves upon the wider sides; but as

these are portions of the diagonal curve, it will not be necessary to show how they are traced, since a mould, formed to the diagonal curve, may be readily applied to draw the curves of the section of the intrados upon either of the sides.

In order to regulate the ribs which form the centering, so that the under edges may be in the curved surface, and to secure them in their places, it will be proper to prepare ridge-pieces curved below, to the line in which the opposite surfaces of the intrados meet each other, and then to fix them in the crown of the vaulted surface. Now, as only the radial sections can be equal to one another, and of the same curve as the diagonal sections, it will be necessary to trace the curves of the intrados in all other vertical planes from either curve in the plane of the diagonal. Hence, having the diagonal curve given, it will be easy to find the plane curves extended on the ridges, so as to range with the surface of the intended intrados of the vault.

For this purpose, let the diagonal curve be *a b c*, *fig.* 1, No. 1. In the curve *a b e* take any number of points, 1, 2, 3, 4, 5, &c., and draw the ordinates, 1 *d*, 2 *e*, 3 *f*, 4 *g*, 5 *h*, &c., meeting the base, *a e*, in the points *d*, *e*, *f*, *g*, *h*, &c. From the centre *a* describe the arcs *d d'*, *e e'*, *f f'*, *g g'*, *h h'*, &c., meeting the plan of the ridge of the summit of the wide opening in the points *d'*, *e'*, *f'*, *g'*, *h'*, and draw the straight lines *d'* 1', *e'* 2', *f'* 3', *g'* 4', *h'* 5', &c., Make the distances *d'* 1', *e'* 2', *f'* 3', *g'* 4', *h'* 5', &c., respectively equal to *d* 1, *e* 2, *f* 3, *g* 4, *h* 5, &c. and through the points 1', 2', 3', 4', 5', &c., draw a curve 1' 2' 3' 4' 5' B'. The point B' being the extremity of a perpendicular from the point *i* in the middle of the axis *a e* of the ellipse, to the straight line *d' i*, equal in length to the semi-axis minor *i b*, and if the point *d'* be in the straight line *m n*, the curve-line 1' 2' 3' 4' 5' B will be the ridge-line at the crown of the intrados of the vault as required.

In the same manner will be found the ridge-curve, *p''* 1'' 3'' 5'' B''. Here the ordinate *i* B'' is as much greater than the ordinate *o'' p''*, as the semi-axis *i b* of the semi-ellipse, in the vertical plane of the diagonal, is greater than the ordinate *u v*. Moreover, the half, *w x*, of the longer side is equal to the portion *a* 1 of the diagonal curve, and the half-curve *s r''* or *t r''* of the shorter side of the severy is equal to the portion *a v* of the diagonal curve; that is to say, the half curve, *w x*, of the longer side, will coincide with the portion *a* 1 of half the diagonal curve, and the half-curve, *s r''* or *t r''*, of the shorter side, will coincide with the portion *a v* of the diagonal curve.

No. 2. is a plan of the centering for one quarter of the severy. Here the curves of the radial ribs, *a b*, *a e*, *a d*, *a c*, &c., are all portions of the half-curve *a b* of the diagonal, the rib *a h* is equal to the curve B'' *p''* No. 1, of the longest ridge of the severy, and the curve *a f*, No. 2, is equal to the curve B' 1', No. 1; the curve of the side of the centre, of which the plan is *f g*, No. 2, will coincide with the half-curve, *w x*, of the longer side of the plan No. 1; and the curve of the side of the centre, of which the plan is *g h*, No. 2, will coincide with the curve of half the shorter *t r''* or *s r''*, No. 1. The parts put in between to strengthen the radial

ribs, will not require to have their edges curved; but if the edges are not curved, they must be under the curved surface.

No. 3, exhibits one of the pillars and one of the portions of the pendants, showing how to draw the curves of the boards for covering the frame of the centering, according to the plan and section No. 4. The capital is laid down to a larger scale at No. 5.

The Principles of Brick-Vaulting, as under the Hall of Christ's Hospital.

291. *Plate* XXIX. *o*, exhibits another species of vaulting, where the intrados are formed by one single surface of revolution, of which the axis is the intersection of the two diagonal planes of the square of the severy. This differs entirely from the preceding, in which every severy consists of four equal surfaces of revolution, meeting each other in vertical planes, which are parallel to and bisect the sides of the severy; each of these equal surfaces of revolution having the axis of the pillar for their axis: moreover, in the preceding vault, the surface forming the intrados, has all the radial sections of each of the four surfaces of revolution concave to the hollow, but convex towards the axis, and the horizontal sections convex towards the hollow, or concave towards the axis: whereas, in the vault we are now about to describe, the surface forming the intrados is every where concave from the hollow below, but the curvature is greater and greater as it recedes from the centre or pole. Vaultings, having for their intrados surfaces of revolution, have been improperly called groins; the reader, however, must observe, that nothing is called a groin, with any degree of propriety, unless that two surfaces which meet each other form a salient angle. The surface employed to form the intrados of this vaulting, is that of a spheroid, generated by the quadrantal curve of an ellipse, revolving upon the semi-axis minor, which is, therefore, the axis of revolution; and, consequently, the figure described by the semi-axis major, will be a circle.

Since all the parallel sections of a conoid are similar figures, whether the solid be described by the revolution of an ellipse, a parabola, or an hyperbola, and since a spheroid is a conoid, therefore all the sections of a spheroid are similar figures, and since all the sections of a spheroid are ellipses, all the parallel sections of a spheroid will be similar ellipses; and because all sections whatever, perpendicular to the plane of a great circle, will have its axis major in that plane, and its semi-axis minor perpendicular thereto, and as every vertical section is parallel to some section through the axis, therefore all vertical sections whatever are similar figures.

Let the plan, on the interior side, be the square *a b c d*, *fig.* 1, No. 1, and, on the exterior side, the square A B C D, of which the sides are parallel to the sides of the square *a b c d*, which forms the plan of the severy, the two squares together comprising the thickness of the walls surrounding the vault. The intersection of the two diagonals is the centre of the circle *a b c d*, which forms the base of the spheroidal intrados; and as the angular points *a*, *b*, *c*, *d*, of the square are in the circumference, the square will be inscribed in the circle.

Let the spheroid be cut by planes along the four right lines *a b*, *b c*, *c d*, *d a*, perpendicular to the plane of the great circle *a b c d*; then the four figures produced by the sections will be all equal and similar, consequently equal and similar to any vertical section passing along the axis, which axis being perpendicular to the plane of projection, is projected into the point *o*, the centre of the circle; and as the vertical section is a semi-ellipse upon the axis major, its projection will necessarily be a straight line.

The section through the axis being given, it is required to find the sections parallel to the axis passing along the right lines *a b*, *b c*, *c d*, *d a*. Let *a d b*, No. 2, be a section through the axis, *a b* being the axis major, and *c d* the semi-axis minor. In *a b* make *c e* equal to *c f*, so that *e f* may be equal to any one of the four right lines *a b*, *b c*, *c d*, *d a*. Join *b d*, and, through the point *f*, draw *f g* parallel to *b d*, meeting the semi-axis minor, *c d*, in the point *g*. Then with the axis major, *e f*, and the semi-axis minor, *c g*, describe the semi-ellipse, *e g f*, and *e g f* will be a plane curve, which may be brought to coincide with any one of the four vertical sections of the faces of the four walls, and the spheroidal surface of the vault. The semi-ellipse *e g f* may thus represent the section over *a d*. No. 3, is the section over *a b*; No. 4 that over *b c*; and No. 5 that over *c d*: each of these being equal and similar to the semi-ellipse *e f g*, No. 2.

Therefore, let these four semi-ellipses be each placed perpendicular to the plane of the circle *a b c d*, so that *e f* may be upon *a d*; *f e*, No. 3, upon *a b*, No. 1; *f e*, No. 4, upon *b c*; and *f e*, No. 5, upon *c d*; and the four curves will then be in the spheroidal surface.

In order to plan out the circular courses of brick-work for this species of rotative vaulting:— From the centre, *o*, No. 1, or point in which the two diagonals meet each other, draw the straight line *o e* perpendicular to *o d*, and make *o e* equal to *c d*, No. 2; with the semi-axis major *o d*, and semi-axis minor *o c*, describe the elliptic quadrant *o c d*, and this curve will be the same as the generating ellipse of the spheroidal surface of the intrados. Divide the curve *e d* into segments which have chords each equal to the breadth of a brick, and from these points draw straight lines, perpendicular to the semi-axis, *o d*. From the centre, *o*, and with the distance between *o* and each point of intersection in the straight line *o d*, draw circles, and these will represent the joint-lines of the brick-work, as in No. 1; where the distances are greater than half the side of the inner square, the circular arcs will be contained, the lines forming the right-angles of the square. No. 6, exhibits an elevation of this vault, and the method of describing the boards.

Fig. 2, is a vault upon an oblong plan, the intrados being a surface of revolution of which, the axis is in the intersection of the two vertical planes passing through each of the diagonals, and is, therefore, of the same species as the preceding. No. 2, is identical with the sections standing upon *a d* and *b c*; and No. 3, with the sections upon *a b* and *d c*. The method of finding the springing curves, as also the method of describing the plan of the joints of the courses of bricks, is the same as practised in *fig.* 1, No. 1, and No. 2. No. 4, is the plan of the centering for one of the eight parts; at the two ends every two opposite parts of the centering will be identical, or constructed of equal and similar parts; but, except in the opposite parts, no

other one of the eight parts can be equal and similarly situated; therefore, two end portions being symmetrical, the opposite end portions will also be symmetrical; and since two of the side portions are symmetrical, the other two side portions will also be symmetrical, and thus the construction of the centering is evident, as far as the arrangement of the pieces.

The figure *a b c* No. 4, is the plan of one of the eighth-parts of the centre of the surface of revolution of the severy of the vault, and its position may either be upon the part *v o c* No. 1, or upon *w o a*. The quadrant, *o g f*, No. 5, is the side of the centering upon *a d*, No. 1; the quadrant *o h i*, of the ellipse, No. 6, is the side of the centering upon *d c*, No. 1; and the quadrant, *o d e*, No. 7, of the ellipse, is the side of the centering standing upon its plan, *a c*, No. 4.

The method of proportioning the quadrants of the ellipse upon their plan, *a b*, *b c*, No. 4 is shown at Nos. 5 and 6, and is as follows:—In No. 5, draw the two straight lines, *o e* and *o d*, forming the right-angle, *e o d*, with each other, and make *o d* equal to the radius of the great circle of the spheroid, that is, equal to any of the four diagonals *o a*, *o b*, *o c*, or *o d*, No. 1; moreover, make *o e*, No. 5, equal to the height of the axis of rotation of the spheroid, and draw the right line *e d*. In *o d*, No. 5, make *o f* equal to *y a* or *y d*, No. 1, that is, equal to *x b* or *x c*, No. 1, and, in No. 5, draw *f g* parallel to *d e*, meeting *o e* in *g*, then *o f* and *o g* are the semi-axes of the quadrant of the ellipse *o g f*, *o f* being the semi-axis major, and *o g* the semi-axis minor of the semi-ellipse upon *a d* or *b c*. In the same manner will be found the quadrant, *o h i*, No. 6. The principle upon which this practice is founded has already been noticed as depending upon this property, that all parallel sections of a spheroid are similar figures.

In order to form the surface of the centering, it will be proper to bend thin boards of wood upon the frame of the centering, in such a manner that the upper surface of the boards may form the surface of revolution. The most convenient form of these boards will be that in which the spheroidal portions will be contained, between two concentric circles in each board. To do this, we must conceive the spheroidal surface to be divided into zones, which will not differ very sensibly from the frustum of a cone; for this purpose, let *o e d* be the quadrant of the ellipse, which is a section of the spheroid in the vertical plane passing along the axis, the semi-axis *o e* of the ellipse being supposed to correspond with the axis of rotation of the spheroid.

Let *e o′ u d*, No. 5, be the curve-line of the section of the spheroid containing the axis, and let *o′ u* be equal to the distance contained between the two concentric circles which terminate the edges of a board in the covering, making the allowance for waste. Join *u o′*, and prolong *u o′* and *o e* to meet each other in *z*, and from the point *z*, with the distances *z o′* and *z u*, describe the arcs *o′ p* and *u v*. To find the length and section of the end of the board, the plan of the board corresponding to the section *o′ u* of the surface must be first found; for this purpose, draw *o′ n* and *u t* each perpendicular to *o d*, meeting *o d* in the points *n* and *t*, and let the semi-axis major, *o d*, No. 4, be parallel to *a b*, No. 5; also, let the semi axis, *e o*, No. 5, meet the point

a, No. 4; then draw, perpendicularly, *n m* and *t s*, to meet *a b*, No. 4, prolonged in the points *m* and *s*. From the point *a*, No. 4, as a centre, with the radii *a m*, *a s*, describe the arcs *m k* and *s q*, intersecting *b c* at *l* and *r*, and *a c* in *k* and *q*. Then *k q r l* is the plan of the board, and *o' u v p*, No. 5, is the form of the board which will cover the plan *k q r l*.

In No. 6, *fig.* 1, the edges of the boards are described for the entire hemispheroid. It must, however, be remembered, that those boards only are entire circles, of which the radii are less than the half side of the inner square; and those of which the radii are greater than the said half side, are portions contained between the lines forming each of the right angles.

No. 6, *fig.* 1, shows the manner of forming a geometrical elevation of the surface of revolution.

Vaults of the forms now described have been introduced under the new hall of Christ's Hospital, London; but though the intrados is formed by a surface of revolution, and the finished effect the same as the vaults here described, the manner of building them was very different from these which have now been described in this treatise; since the courses of these here described have their joints in conical surfaces, and, consequently, the joint-lines in the surfaces of revolution are circles, with their common axis perpendicular to the great circle of the spheroid; whereas, those under the hall of Christ's Hospital are laid diagonally, and meet each other in vertical planes parallel to the sides of the severy.

Principles of Brick-Vaulting similar to that described by Mr. Tappen.

292. *Plate* XXIX. *p*, *fig.* 1, No. 1, exhibits a plan with two severies of groin vaults, with parallel diagonal cylindrical bands intersecting each other, in planes parallel to the diagonal plane. If the plan were square, these parallel diagonal cylindrical bands would intersect each other at right-angles; but, as the plan of the severies is oblong, these bands intersect each other at oblique angles. Whatever be the position in which the groins intersect each other, the right-angles of the piers must always be reduced, so as to make each an octagon by four additional faces parallel to the vertical planes which contain the groined lines.

In the lower severy, No. 1, let *a k i* 4 be the one, and *b g h f* the other, of the parallel bands. We shall here suppose that the section upon the narrow side is a semi-circle, given in order to find the groin in the plane of the diagonal expressed by the right line *f b* upon the plan, and consequently to find also the equal and parallel groin in the plane of the diagonal upon the right line *h g* in the plan. Suppose the point *c* is in the middle of the given semi-circular arc. At any convenient distance from *c* take the points *d*, *e*, &c., and draw the right lines *c n*, *d o*, *e p*, &c., perpendicular to *a b*, the base line of the rib, meeting it in the points *n*, *o*, *p*. Draw the right lines *n l*, *o q*, *p r*, &c., perpendicular to *a b*, or parallel to the long side of the plan of the severy to meet *f b* in the points *l*, *q*, *r*, and draw the right lines *l m*, *q r*, *r w*, &c., parallel to *a k* or 4 *i*, meeting *h g* in the points *m*, *r*, *w*, &c. Draw the right lines *l u*, *q t*, *r s*, &c., perpendicular to *f b*, and make the lengths *l u*, *q t*, *r s*, &c., respectively equal to *n c*, *o d*, *p e*, &c., and

through the points thus found draw the elliptic curve *u t s....b*, which will be the groin standing upon *l b* or *m g*. Let *k g* be the right line upon which a vertical section is to stand. Draw the right lines, *m x*, *v y*, *w z*, &c., perpendicular to *g k*, or parallel to the narrow side of the severy, meeting *k g* in the points *x*, *y*, *z*, &c., and draw the right lines *x* 1, *y* 2, *z* 3, &c., perpendicular to *k g*, and make the lengths of the right lines, *x* 1, *y* 2, *z* 3, &c., equal to the lengths *n e*, *o d*, *p c*, &c., and through the points 1, 2, 3....*g*, draw the curve 1, 2, 3....*g*, which will be the section required.

Fig. 1, No. 2, is an elevation corresponding to the narrow side of a severy.

CHAPTER V.

ON THE CONSTRUCTION OF BRICK NICHES.

293. A Niche is a recess in a wall, either for ornament, or for the purpose of containing a statue.

The surfaces of niches are generally concave. The most elegant are those which are formed by cylindrical and spherical surfaces, the back being formed by the cylindrical surface, and the canopy, or head, by the spherical surface. The portion used of the cylindric surface is either that which would be terminated by a diametrical plane, or which would be a less portion of the surface terminated by a plane parallel to the axis, the terminating plane being the face of the wall. The axis of the cylindric back is vertical, and the centre of the sphere is in the upper extremity of the axis of the cylinder, and the spherical and cylindrical surfaces meet each other in a great circle of the sphere contained in a plane perpendicular to the axis of the cylinder. The bottom of the niche is generally horizontal, sometimes in the plane of the floor, but more commonly raised above the plane of the floor.

The niche, *figure* 2, *plate* XXIX. *p*, is taken from that in the front of the green-house, Kensington-Gardens, which is one of the best-executed pieces of brick-work in this country. Numbers 2 and 3 exhibit the bond of the courses laid according to the Flemish manner; No. 4 exhibits a vertical section through the centre of the spherical surface, and perpendicular to the face of the wall.

294. The practice of constructing a niche in brick-work is the most difficult part of the profession, on account of the very thin size which the bricks are obliged to be reduced down to the inner circle, as they cannot extend beyond the thickness of one brick in the arch surrounding the crown, it being usual, as well as much the neatest method, to make all the courses radiate.

The most familiar way to reduce this method to practice, is to draw the front, back, &c., and make a templet of paste-board. After the arch has been divided into the number of bricks, observe that one templet for every radiating course will answer the front, and one for the side of the brick. At the top of the straight part, from which the niche takes its spring, make a circle, 8 or 9 inches diameter, and cut this, as well as the former, out of pasteboard, and divide it into the same number of parts as the outward circle terminating in the front of the wall. From this will be found the width of the front-templet at the bottom. The reason of introducing this inner circle is to cut off the thin ends at their conjunction, as they would otherwise require to terminate in straight lines in the centre of the niche, and therefore the bricks would be formed into such very acute angles, that they would be liable to break off in working them; it being impossible to make the thin ends stand at a thickness less than half an inch.

Within the inner circle, the bricks must be laid so that their longest dimensions may be horizontal and parallel to the plane of the front from which the niche recedes. It will be necessary to have one templet made convex, in order to try the faces of the bricks, as well as to set them after being properly shaped. The stone upon which the faces of the bricks are rubbed, must be cut at one end in the exact form of the niche, or otherwise it will be impossible to face them as they ought to be. The level of the flat sides of the bricks will be obtained by dividing the back into an equal number of equal parts as in the front, and the radiating lines must be all struck from the centre. From the circle of the front and the face of the niche set a bevel, which will answer to the sides of the whole, always taking care that the bricks hold their full gauge at the back; for if this circumstance is neglected, much trouble will attend the execution. Works of this nature require a good price, in proportion to the great skill and attention required in the execution.

The portion of brick-work, which shows a semi-circle in the front, is called by the name of Trompilion; this is made up of several courses, of which the fronts of the bricks must be all curved, so that, when placed and fixed, they must form the true spherical surface in which it was intended that the niche should form.

CHAPTER VI.

ON THE CONSTRUCTION OF TUNNELS AND DRAINS.

General Observations.

295. A Tunnel is an excavation made under ground, terminating at each extremity in the surface of the earth, for the purpose of giving passage for some moveable thing or things.

Such a communication would either be found convenient or necessary, where some intervening object would render the conveyance dangerous or extremely expensive, or even, in some cases, impossible. By means of a tunnel, a stream of water may be conducted from a given entrance on one side of a hill to a given outlet on the other; or a passage of communication between the opposite shores of a deep river, without interrupting its navigation, may be effected.

If the object of the tunnel be to conduct vessels by means of water, it is evident that the bed of the fluid must be nearly in a horizontal plane, and if it be required to effect the passage in the least time, its direction ought to be in a right line. This mode of communication would also be found necessary in conducting a roadway through a hill, which would otherwise be found insurmountable.

The figure of the section of such an aperture will depend greatly upon the soil through which it is cut; but whatever be the form of the right section through any particular point, the same figure must invariably continue, unless the quality of the substance is found to vary. In this case, the figure of the section must be such as will meet every contingency. The sides of the aperture ought always to be lined with brick or stone, and the top ought to be arched. If the soil be sand, a tunnel cannot be constructed so as to support the superincumbent mass; and therefore, in this case, such a conveyance, though ever so desirable, ought never to be attempted. If the soil be clay or solid earth, the figure of the right section of the tunnel must be of such a form all round that the mutual pressure upon the parts may balance one another; or by making allowance for the convenience of practical operations, the figure ought to be as near as possible to the curve of equilibrium for the support of such a surrounding mass. If the substance be rock through which a tunnel is to be cut, it will not be necessary to form an arch all round, the bottom may be paved in the usual manner, and the sides which form walls may be built upon the solid rock.

In executing a tunnel, it is evident that no more of the ground should be cut away than is absolutely necessary to effect a part of sufficient length for the operation of walling and arching, and thus the building and the excavation must be carried on alternately at regular intervals. The lengths excavated at a time before the brick-work is built must depend upon the nature of the ground, and may be from 3 or 4, to 7 or 8, feet, in the line of direction of the tunnel, observing the quality of the ground with the utmost circumspection, so as not to endanger its falling by taking away too much at a time.

Instead of making one continued arch all round the tunnel, and in order to save the materials, the bottoms are most frequently constructed in the figure of an inverted arch, being a segment considerably less than a semi-circle. The sides and top, however, ought to be carried round from one extremity of the pavement, or inverted arch, to the other extremity, in such a curve as will be most suitable to the surrounding pressure of the earth, observing to form a commodious aperture for passage. With regard to the supporting of the earth at the crown in the most sufficient manner, it will depend upon the nature of the soil, and upon the circum-

stances attending the execution of the work. This will be best understood by a reference to particular examples: in general, however, this may be done by horizontal bars placed in the direction of the tunnel, having their remote ends inserted a foot or more in the solid earth, and their other ends supported by the portion of the arch last constructed, or by means of upright shores from the pavement.

In these constructions, it is necessary that the joints should be as close as possible; therefore, in order to effect this with brick materials, as all the opposite faces of a brick are in parallel planes, the joints cannot radiate as they ought to do; hence the opposite sides of any number of courses built with bricks closely-jointed, would also be comprised between parallel planes, and consequently such a position of bricks could never form an arch. In order, however, to render the use of common bricks practicable, the arch would require to have a very great radius of curvature, and only a few courses (their number depending upon that curvature) built at a time between two courses of wedged-bricks made for the purpose; these wedged-bricks must be so constructed as to have their sides, which comprise the intervals for the common bricks, in parallel planes. The figure of the arch would thus become a polygon of a great number of sides, the general effect of the intrados could not therefore be distinguished from a curved surface. The skew-backs at the extremities of the pavement may be made of hard stone, so as to answer to the radiations of the brick-work upon each side.

Description of the Tunnel at the Regent's Canal.

296. *Plate* XXIX. *g*, *figures* 4 and 5, exhibits a section of this tunnel, from a drawing by Mr. Provis, who received a premium of one hundred guineas from the company appointed to direct the work. By inspecting *fig.* 4, it will be perceived that the curvature of the bottom, top, and sides, are struck from four centres; the thickness of the bottom is $1\frac{1}{2}$ bricks in length, and all the other parts two bricks. The bricks are of the common sort, with the exception of one course in eight in the bottom and sides, and one course in six in the arch at the top. These bricks which separate the common bricks radiate in such a manner, as to leave the sides of the intervals between every two of them in parallel planes, so that each interval may contain the number of common bricks between the parallel plane surfaces of the radiating ones: these radiating bricks were all made for the express purpose. As common bricks have their sides in parallel planes, and as it is of the greatest consequence that the joints of mortar should be as thin as possible, particularly on the lower part adjacent to the convex surface, forming the ceiling or soffit of the arch, which has to sustain the greatest pressure, these radiating bricks are absolutely necessary to prevent the joints from departing too much from the radiating lines.

In executing a tunnel, it is essential that no more of the ground should be cut away than is absolutely necessary; having excavated the first length, the leading frames must be already pre-

pared similar to those shown in *fig.* 5; they may be made of 1½-inch deal; then having correctly obtained the level of the bottom of the tunnel, and the central range or line of direction which is intended to pass from one extremity of the tunnel to the other, lay the first course of brick-work at the bottom by means of this line, with two or three courses on each side of it, in order to give it a firm support as at I, *fig.* 5. Upon these courses set up the leading frame at each end, the centre of the under-curve of which must coincide with the line of direction on the top of the middle course of bricks. Having placed the leading frames in their proper positions, secure them to their places as exhibited in *fig.* 5; then execute the brick-work of the bottom on each side of the central or directing courses, making the joints between the bricks with as thin a substance of mortar as possible, not forgetting to put in the courses of wedged or radiating bricks at their proper distances from each other; and upon the margins at E, E, *fig.* 4, lay the skew-backs, which may be made either of bricks or stones, and upon the skew-backs carry up the curved sides or walls as high as the tops of the leading frames, observing, as before, to insert the wedged course of bricks in their proper places, and if any space should remain between the natural ground and the brick-work, fill the vacuity up with solid earth, well condensed by ramming it, or otherwise the space must be wrought up with solid brick-work.

In the course of these operations, the next thing to be done is to set the centre for the arch at the top. It must consist of two single ribs without any attached covering, and may be of any common construction, so as to be of the proper curve and sufficiently strong. As the bricklayers must stand below the arch, in order to turn it, instead of being above it, the covering of the centre must consist of single straight pieces of wood, about three inches square, and must be laid loose on the circular ribs by one at a time as the courses proceed, till the work arrives as high as the supporting bars F, F, &c., which must be taken out one at a time, as the brick-work approaches them, taking care all the way to stop up firmly every vacuity that may be between the top of the brick-work of the arch and the soil immediately above it. The arch is at last keyed in with wedged-bricks, which must be driven upwards very tight.

When the first length is completed, the leading frames and centre are moved out of the way, in order that the miners may proceed to excavate the next length, which, when done, the bricklayers proceed again as before, with this difference, that only one leading frame is required for the next and each succeeding length; as the brick-work, already executed, will answer all the purposes of a second leading frame.

Fig. 4, shows the arch as completely finished; and *fig.* 5, exhibits a section of the hollow as excavated for one of the single lengths, at one interval of time, before the brick-work is built; the length thus excavated at once must depend upon the nature of the ground, and may be from three to eight feet, being careful not to endanger the falling in of the ground by taking too great length at a time. The horizontal bars, to support the superincumbent earth during the excavation and building of the brick-work, are exhibited at F, F, F, &c. The leading frames,

which direct the shape or figure of the section of the tunnel is exhibited at A, B, C, D, *fig.* 5. This is the main guide by which the bricklayers are enabled to conduct their work in the process of building: the plumb-line, which directs the position of the leading frames, is exhibited at GH; at I, is shown the courses of brick, in order to support the middle of the leading frames, and on which the line of direction for setting them is drawn; the supports for the two extremities of the leading frame are shown at J, J. These are to be taken away when the bottom is so far laid as to give sufficient stability for the leading frames. The bars F, F, &c., are fixed by inserting one end a foot or more into the solid earth, and the other end is supported by the arch last turned, or may be supported by upright shores from the bottom.

In *fig.* 4, which shows the arch as complete, the radiating bricks are shown at *a*, *b*, *c*, &c. for the inverted arch; at *d*, *e*, *f*, &c. and *g*, *h*, *i*, &c., for the sides; and at *k*, *l*, *m*, &c. and *n*, *o*, *p*, &c., for the arch at the top. The centre for describing the inverted arch is shown at L; the centres for describing the side-arches *n o*, *n o*, are shown at *m*, *m*; and lastly, that for describing the arch at the top is shown at *p*. It is obvious that this point must be in the intersection of the two right-lines, *m n*, *m n*, in order that the two curves may meet each other without making angles at the points *n*, *n*, which would not only destroy but weaken the figure of the tunnel. The beauty and regular gradation of the curve tends greatly to promote the strength and durability of the work.

In the construction of tunnels, the whole of the mortar employed should be made of the best water-cement, otherwise it will very soon be brought to a state of decay, and would require to be often repaired; and therefore eventually would become very expensive, a disagreeable circumstance which may be avoided by anticipating it in the outset, and thus providing against it in the execution.

Tunnel under the Thames, from Rotherhithe to Wapping.

297. This bold design, to effect a communication of the opposite shores of this very deep and navigable river, was undertaken by Mr. Brunel, an engineer of eminence, who, undismayed by the failure of some attempts which had been made to accomplish the same end, completed a design for the execution of a tunnel beneath the river Thames.

This enterprising design, from the rational hope of remuneration, did not continue long without patronage. A bill to incorporate a company for the execution of the proposition under Mr. Brunel's superintendance received the royal assent, on the 24th June, 1824. The examination of the bed of the river, the selection of the most eligible position, the purchase of property, the preparation of the novel machinery, &c. &c. occupied the rest of the year.

The soundings taken along the proposed line across the river, gave 12 feet water at the lowest tides, and 36 at the highest, in the deepest parts. The bed was found to be a stratum of sand, about 3 feet 8 inches thick, laying upon a stratum composed of sand and clay; thence the top of the excavation was a bed of tenacious clay. The descending order of the strata at the

lower part of this bed in which the tunnel is executed was as follows:—A bed of stiff blue clay, about 2 feet in thickness; a bed of silt, 7 feet; silt mixed with shells, 7 feet; indurated clay, 3 feet; silt and gravel-stones, 3 feet.

The tunnel was begun early in the year 1825; and the design consists of a square mass of brick-work, 37 feet by 22, comprising the arched passages, each of the width of 16 feet 4 inches. Each carriage-road is 13 feet 6 inches wide, and the height of each aperture above the road-way 15 feet 6 inches. The extreme sides are 3 feet in thickness, and the arches 2 feet 3 inches. The arched passages are divided by a wall of great strength; and this division-wall is perforated by a range of arcades, of which a certain number of them, placed at regular intervals, are so wide that vehicles may pass from one carriage-way to the other. The central wall was built solid for the greater security of the work, and afterwards perforated. Under each passage is turned an inverted arch, 2 feet 3 inches in thickness; the external wall rests upon one extremity of this arch, and half of the middle wall upon the other. Over the invert rests the Macadamized roads, terminating with commodious foot-paths on the sides: all the joints between the bricks are laid with cement.

The foundations were all laid upon very strong beech-planks, which seem to have answered the purpose extremely well, since there has been no instance of any sinking or settlement of any kind.

It was intended that the foot-passengers should enter the tunnel from either side of the river, by means of a winding-stair placed in a circular shaft. The distance of the two shafts for the passengers was intended to be 1300 feet, the width of the river being 1000 feet, from wharf to wharf; and that the descents for the carriages should be circular. Before the tunnel could be begun, it was necessary to get down to the depth at which the level of the bottom of the entrance was to commence. For this purpose a cylindrical wall, 40 feet in height, 3 feet in thickness, and 50 feet in diameter, was constructed, so that, when sunk, to become the lining of the shaft. This circular wall rested upon a wooden curb shod with cast-iron base, of which the lower edges was formed into an acute angle in the manner of a chisel, and the top was secured by another wooden curb, which was joined to the bottom one by means of iron rods. The brick-work was built with the utmost care on the surface of the ground immediately over the place which was intended for the shaft.

In the upper part of the shaft, a steam-engine of 36-horse power was constructed, with a boiler, fire-place, &c., for the purpose of freeing the bottom of water, and lifting the excavated soil.

The first brick of the tower was laid on the 2d of March, 1825, by Wm. Smith, Esq., M. P. for Norwich, and on the 1st of April following, the excavation commenced within its enclosure. As they proceeded, this immense structure, with its engine, &c., continued to descend vertically, without accident, for twenty days, through successive strata of gravel, &c., and when it had descended 37 feet from the surface, it rested upon a solid bed of clay. It was there permitted to remain; but the excavation was continued, and the cylindric-wall under-built to the depth of

21 feet. At this level the diameter was reduced to 25 feet, and another cylindric-wall inserted, sunk 20 feet more.

This lower part was intended as a tank, or receptacle for the drainage-water, into which were carried the suction-pipes of the engine-pump, for the purpose of carrying it off.

The total height of the brick-work of this shaft was therefore $40+21+20=81$ feet, 61 of which are of 50 feet diameter, and 20 of 25 feet. It consumed about 260,000 bricks, and 1200 barrels of cement. The weight of this construction is about 900 tons. The cylindrical cavity is intended eventually as the stair-case for persons on foot. Near it, a little to the southward, will be built the cylindrical shaft of 160 feet diameter, by which carriages are to ascend and descend, so as not to exceed in any part a greater declivity than that of Waterloo-Place, Pall-Mall.

Though the principle of sinking this shaft was familiar to every well-digger, and to every miner, yet, from its vast diameter and proportional dimensions, it is considered as the greatest work of the kind ever yet attempted, as it demanded a more than ordinary degree of skill and intrepidity on the part of the engineer, in order to secure the success of the work.

At the bottom of this shaft a lateral excavation was made for commencing the tunnel; and from thence the constant protection and support of the soil, and the great weight of water upon it, was effected by means of a strong iron frame, consisting of several moveable vertical parts, the whole of which was called by Mr. Brunel by the name of a *shield*, weighing 120 tons, being 37 feet in width, 22 in height, and 8 feet in depth, and containing thirty-six workmen. It consisted of twelve compartments, which were advanced alternately and independently of each other, having each three cells, of which the floors serve constantly as a scaffold for the miners and bricklayers.

The front of the shield is placed against the face of the soil to be excavated; and, by means of moveable boards placed upon it, the workman can, by taking away the board, remove any part of the earth behind at his discretion, and when done, he places the board against the new vertical surface now exposed, and the board by this means becomes in advance of the box, and is kept in its place by props, which have their supports by the face of the brick-work in the rear. When he has thus proceeded with all the boards, it will be evident that an excavation will have been made equal to the area of the front of the shield, and of a certain depth, and that the boards will all be in advance equal to this depth. The box, by means of screws, is forced forward to the boards, and the operation of excavation recommences, and so on, observing that at every time the excavation is made, the brick-work is immediately executed all round close to the shield, and thus the security of the work is preserved.

The work proceeded for several months, at the rate of about two feet in twenty-four hours, displacing from 90 to about 100 tons of earth, which were lifted to the surface by the engine. In each foot in length of the tunnel 5,500 bricks were used. On the 2d of March it had advanced 470 feet, which is about one-third of the whole length. About 11,000 bricks, laid in cement, were used every day, and the labour of one hundred men was constantly kept up.

A main from the gas-works is laid along the floor, and conveys the gas to columns placed in the connecting arches as they are formed; and from these branches both the road-ways are illuminated, which produce in the eyes of the spectator, at his entrance, a most extraordinary and beautiful gradation in the perspective succession. The total freedom from water is preserved by drains underneath, which empty themselves into the tank under the engine at the bottom of the shaft.

298. Though Mr. Brunel has conducted this work with very great ability, by numerous expedients to facilitate the progress, and to anticipate the difficulties of this extraordinary undertaking, these qualities were destined to a very severe trial. On the 18th of May, 1827, at a distance of 544 feet from the commencement of the tunnel, in the cylindric wall of the shaft, the water of the river found its way through a portion of loose earth, and entered the tunnel through the shield, with a velocity and volume which filled the hollow and the shaft in fifteen minutes. This happened while the workmen were at their duties, but no lives were lost. In this eruption about 1,000 tons of loose soil and rubbish descended into the tunnel. This breach was examined by means of a diving-bell, and repaired by depositing about 15,000 cubic yards of clay, in bags, so as to fill up the cavity complete. The water was then pumped out, and the brickwork surrounding each aperture was found very slightly injured. In the latter part of September the works recommenced; but, after the length had been extended 52 feet farther, and the dangerous part passed, on the 12th of January, 1828, the water of the river broke in and passed through the shield a second time; the tunnel was filled in less than ten minutes, and the rush of water brought in with it a current of air that put out all the lights: six of the workmen, being unable to extricate themselves, were drowned, the rest escaped. The point at which this eruption happened occurred at the distance of 600 feet from the shaft. This unfortunate eruption has also been perfectly stopped; and, though the tunnel descends 3 feet in 100, into the excavation, in one part, towards the middle of the river, had approached within 10 feet of the water above it.

These events, though much as it must be deplored, as tending to check the progress of the work, yet prove in a manner highly satisfactory, that no event of this nature can offer any impediment which cannot be surmounted.

The sympathy which these misfortunes have so justly excited, together with the increased admiration which the overcoming of such difficulties has produced, induces a hope that the progress in future will be a national concern, and that the subscribers will be relieved from farther outlay by the munificent hand of government.

The whole cost of the tunnel was originally calculated by Mr. Brunel to be £160,000; but the work has been attended with so many contingencies, independently of the expense incurred by the last accident, the expenditure before was £157,000., of which about £38,000. has been laid out in the purchase of premises and machinery, and £118,500. in the works. The directors state that about £75,000. will be necessary to complete the tunnel to the north embankment.

Plate XXX. *fig.* 1, exhibits a transverse section of the river Thames, passing longitudinally along the tunnel, and through the substance between the bed of the river and the excavation, with the sections of the shafts for the descending and ascending of carriages and foot-passengers. The plan of the shafts and tunnel are exhibited in *fig.* 2.

Fig. 3, exhibits an elevation of the shield in which three men are represented at work in one of the compartments; and *fig.* 4 is an elevation of the side of the shield, and in the longitudinal direction of the tunnel. The whole weight of this shield was 120 tons.

Fig. 5, a transverse section through the two apertures of the tunnel, and through the summit of one of the arches of the division-wall, showing the representations of a loaded carriage and foot-passengers to and fro.

Plate XXXI. *fig.* 1, exhibits a view of a part of the cylindrical brick-wall, the other part being taken down, in order to show how the curbs which secure the extremities of the brick-work are connected to each other by means of rods made of iron and wood alternately, placed and fixed to the curbs by means of screws. This, as has been explained, was sunk by continually taking away the earth from beneath, and rested at intervals, so that the axis of the cylinder might be perpendicular at each descent. During the time of making any one descent, when a certain portion of the ground was taken away from under the wall, this portion was supported in the middle by blocks and wedged tight to the under side of the curb; after this was done, another portion of the soil was dug away, and the under side was again supported by wedges in the same manner, and so on all round, till the excavation was completed; and then, when the wedges were slackened, and the blocks removed, the mass descended through one step, and this operation was done in every step.

Fig. 2, shows a portion of a section of the bed of the river containing a transverse section of the excavation of the tunnel, and elevation of the six compartments of the shield. This section shows also a profile of the cavity formed by the irruption of the water, the manner in which it was filled by the clay-bags, and how the tarpauling above the clay-bags was kept down, by means of cast-iron kentledge, and, above all, the covering of gravel for securing the whole.

Fig. 3 exhibits a section, as in *fig.* 2, but without the cavity being filled with the clay-bags, in order to show the state of the bed of the river after the irruption more clearly than *fig.* 2.

Various other Designs for the Sections of Tunnels, Sewers, Culverts, and Drains.

299. *Fig.* 7, *plate* XXXII, the section of a Tunnel, in which the road-way is sufficiently broad as to admit of carriages to pass each other with ease and without danger. The breadth of the road-way is 28 feet, and that of each of the foot-paths 7 feet, the whole breadth being 42 feet. The entire height between the middle of the head-arch and that of the inverted arch is 21 feet, and the height between the summit of the pavement in the carriage-way and the

summit of the arch is 18 feet. *Fig.* 8, is a design for another tunnel, containing carriage and foot-ways, the whole width at the widest part being 24 feet. *Fig.* 7, is adapted to those situations in which the surface of the ground is not at a very great distance from the hollow of the tunnel; and *fig.* 8, is adapted to a situation where the pressure by the weight above is very great.

Fig. 2, is adapted to a culvert for passing a large body of water, as a mill-dam, or the like. *Fig.* 1, section of the brick-work of a common or main sewer. *Figures* 3 and 5, are the sections of smaller sewers or drains. *Fig.* 4, exhibits the section of a small barrel-drain; and *fig.* 6, shows the section of one of the smallest drains in use.

All these designs, excepting *fig.* 8, may either be constructed of brick or stone, according as the one or the other is most easily procured. In all cases, the planes of the joints should be perpendicular to the visible surface of the tunnel, whether the material used be brick or stone; by this means the work will not only be easier to execute, but at the same time it will require fewer materials and will be much stronger, and, consequently, much less expensive than when the joints are placed obliquely to the visible surface of the brick-work adjacent to the aperture or void of the tunnel.

Though a uniform figure for the form of the right section of a tunnel is both stronger and more elegant than one that is compounded of the arcs of circles; yet, if the variation is not very sudden in any place, to execute the whole of an arch of variable curvature, in several or in many portions of circular arcs, having their radii varying gradually from each other, will be very convenient, as such an approximation will not be perceptible in the whole design. It must, however, be observed, that the arcs on each side of every point of junction must have their centres in the same straight line, and that this straight line must pass through the point of junction; that is to say, the three points, viz. the centres of the two arcs, and the point of junction of the arcs, must be all in the same straight line. If this circumstance is not attended to, the beauty and strength of the work will be greatly deteriorated, as the curvature of the section of the arch will be deficient in point of continuity, and this will produce a very unsightly effect on the eye in the general appearance of the work, by crippling it in sudden gradations. This unpleasant effect must therefore be carefully guarded against, so that nothing but beauty and harmony may result from the execution of the design; and this will not only give satisfaction to the workman who executes, and to his employer, but also to the public, who are ultimately to judge of the general effect of the design.

CHAPTER VII.

ON THE CONSTRUCTION OF OVENS, BOILER FIRE-PLACES, AND OF THE SETTING OF COPPERS.

300. The section of the roof of the oven, on the old principle, for the use of bakers, was usually of an oval figure, being arched over at top in the figure of an ellipsoid; the sides and bottom of brick, tiles, and lime, with a door in front; and at the upper part, an inclosed closet, with an iron grating, for the tins to stand on, called the *Proving Oven*. To heat such ovens, fagots are introduced and burnt to ashes, which are then removed, and the bottom cleaned out. This operation requires some time, during which much of the heat escapes. A still further length of time is required for putting in the bread, and unless much more fuel is expended than is really necessary, in heating an oven upon this principle, it becomes chilled before the loaves are all set in, and they are, therefore, by this means, very much injured.

To remedy this inconvenience, many ovens have latterly been built upon a pavement supported upon solid brick-work, with a door of iron, furnished with a damper to carry off the steam as it rises, and heated with fossil coal. On one side is a fire-place or furnace, with grating, ash-hole, and iron-door, similar to that for supporting a copper, with a partition to separate it from the oven, and open at one end. Over this is a middling-sized copper, or boiler, with a cock at the bottom, and on one side of it is placed the proving oven; the whole being faced with brick and plaster.

When this oven is required to be heated, the boiler is filled with water, and the fire being kindled, the flame spreads around the oven, in a circular direction, all over its concavity, and renders it as hot as if heated with wood, without causing dirt or ill smell, while the smoke escapes through an aperture, which may pass into the kitchen-chimney. When the coal is burnt to a cinder, there is no necessity for removing it, as it prevents the oven from cooling while the bread is setting in, and keeps up a regular heat till the door is closed. The advantages of an oven built upon this principle, are too obvious to require comment.

Plate XXXIII. exhibits, in detail, the improved plan of an oven, on the new construction. It has been communicated by Mr. Elsam, the Architect, under whose directions it has been constructed in various public buildings in different parts of the United Kingdom.

Figure 1 is the plan of the oven. The fire is put into the furnace, A, and is supported upon wrought-iron bars, which are fixed an inch and a half below the level of the oven, to prevent the cinders from entering it. The outside of the furnace is shut with two cast-iron doors (1, 2, in plan). The ashes fall into the ash-pit beneath, B, (*fig.* 2,) the door of which is marked 3, in the elevation (*fig.* 3).

While the coals are burning, the mouth of the oven is inclosed only by the curved cast-iron door, or blower, B, shown in the section of the oven, (*fig.* 4,) and elevation, (*fig.* 10,) and which is so shaped in order to make a proper passage for the smoke to the flue, C. This door, or blower, is not hung, but is put up and taken away by hand, as may be required.

When the oven is sufficiently hot, a man, placed at its mouth, with the iron bar, E, (*fig.* 5,) slides the cast-iron stopper, D, (*fig.* 1 and 6,) to the angle, F, where it stops, as shown by the dotted lines; then going to the mouth of the furnace, he hooks the crooked part, G, of the same iron bar, (*fig.* 5,) into the circular hole of the stopper, H, (*fig.* 7,) and pulls the fillet, IIIII, (*fig.* 8,) into the frame of the furnace, upon which it fits. This stopper is made to slide, but not in a groove, as the cinders might sometimes prevent its being shut.

Figure 8, represents an iron frame, to be fixed round the mouth of the inside of the furnace. The opening of the mouth should be one foot two inches wide, and one foot high, and to be made to receive the fillets of the stopper, III.

The door, K, (*fig.* 4,) is fastened to an iron chain, and is raised or let down, at pleasure, by turning the lever, L, (*figures* 4, 10.) In order to prevent the heat from escaping while the bread is putting in, the mouth of the oven must be made as small as possible. To the handle of the lever is hung an iron pin, with a chain, and over it is a semi-circular iron plate, fastened to the wall, with five holes drilled in it to receive the pin, which, by this mean, will regulate the height of the door, K, at pleasure.

When bread is baking, the curved door, B, not being then wanted, is taken away; and the two doors of the oven, with the two doors of the furnace, are shut up.

At the top of the furnace, M, (*fig.* 4,) is a small flue, about three inches square, communicating with the flue of the oven. The use of this small flue is to leave a passage for the sulphur that may remain in the ashes, and might injure the bread while baking. The communication of this small flue of the oven is opened or shut by means of an iron slider, N, (*fig.* 10.) Over the furnace is a niche, (*fig.* 3,) with a boiler of hot water.

It has been observed that, in ovens on this construction, whatever be the dimensions of the fire-place, it is always proper to set the bars eight or ten inches in from the door, by this means a supply of coals will be kept warming before they are pushed forward into the fire. The importance of this preparation is known to those who have attended to the effect of every fresh supply of coals to the boilers of steam-engines, as it instantly stops the boiling, unless this precaution is attended to. It also prevents, in a great measure, the cold air getting in between the door and frame of the fire-place, which frequently happens, from the difficulty of fitting iron doors to iron frames.

Ovens, on the improved construction, will hold, according to their size, as follows:—

Eight feet wide, and seven feet deep, eight bushels of bread.

Nine feet wide, and seven and a half feet deep, ten bushels.

Ten feet wide, and eight and a half feet deep, twelve bushels.

If required to hold less than eight bushels, or more than twelve, the proportions, of course, must vary accordingly.

The oven represented in the plate is eight feet wide and seven deep; and, therefore, as stated above, it is adapted for eight bushels of bread. The fire-hole, or furnace, exhibited in *fig.* 1, enters the oven in a diagonal direction with the farthest corner; the sides of the oven are carried nearly straight, and turned as sharp as possible at the haunch and shoulder, this form being supposed better calculated to retain the heat than any other: the flue is immediately over the entrance, as shown in *figures* 1 and 4. Welsh lumps, or fire-bricks, are used for the furnace. In works of this nature, it is usual to introduce a considerable quantity of old iron hoops, more especially around and over the oven, in order to keep the work together. This precaution is advisable on all occasions where great heat is required.

In building the oven, one end of the crown is turned with bricks, as shown in the section, *fig.* 4; and the centering, for building the brick-work upon, is formed by filling the void with sand, clay, or rubbish, which must be well trodden down, and formed to the shape or figure of the crown. When the upper work is finished, the sand, clay, or rubbish, which formed the centering, must be dug out by the mouth of the oven.

Other particulars will be found in the explanation of the terms used by Bricklayers and Plasterers.

Of Boiler Fire-Places.

301. *Plate* XXXIV. shows the method of constructing a series of kitchen fire-places, for heating boilers, stew-pans, and other culinary apparatus.

Fig. 1 represents a section, and *fig.* 2, a plan of a double-boiler fire-place; the vertical section is taken through the centre of the grate, as shewn by the dotted line, *a*, *a*.

In this construction, one boiler is placed immediately over the grate, and the other is placed over the space seen at *b*; the space *b* is made sufficiently capacious to admit a large portion of the heated current of air, the direction of which is shewn by darts, the flue being so constructed, as to completely envelope the external surface of the two boilers. If the flues were made all the way along their course of equal capacity with the space contained around the grate, it is very clear that when the air became rarified by the combustion of the fuel, it would move in every part with an equal velocity, and the greatest portion of the heat would escape, without being imparted to the vessel and its contents intended to be heated. In order to prevent this, the area of the flue is contracted at *c*, by which means the heated air is detained much longer under the bottom of the boiler, and impinging upon the surface of the vessel, tends to heat it in the most advantageous manner, it being a well-known fact, that heat is best communicated by ascent; therefore it will, at all times, be advantageous to detain the heated current as long as possible, while it is covered by the under surface of the boiler. These

reasons, if duly attended to, will, in every case, suggest to the practical bricklayer the most advantageous situation to construct the check or diminished area of the passage for the heated current.

In cases where very great economy is requisite, as in steam-engine boilers, &c., the advantage of the ascending property of heat is so well understood by engineers, that they make the sides of their boilers project so as to form the upper surface of the enveloping flue, by which means they not only avail themselves of the lateral heat of the current, but also of that most important one before stated, namely, the ascending property.

The sides around the grate, shewn at *d, d, d, d, d,* should rise in a sloping direction, so as to accommodate the space to the rarified state of the air, after it has been heated by the combustion of the fuel; and as these sides will have to sustain the greatest action of the heat, they being many times covered with the ignited fuel, it is absolutely requisite that they should be formed of the best fire-bricks, and set in Stourbridge clay, or fire-loam, mixed with ground-clinkers from smiths' forges, which, when heated, will form a semi-vitrified mass that will bind and unite the whole mass firmly together. In all cases, where it can be admitted, the approach to the narrowed passage of the current should be made to slope gradually upwards, which will assist to contract the current, like a funnel, at the same time that such an effect is greatly assisted by changing the direction of the heated medium.

In the construction of every kind of fire-place, where it is intended that the heated air should be made to strike or impinge against any vessel, in order to raise the temperature of its contents, it will be of the greatest importance to have all the brick-work done in the most solid manner possible, as nothing can be more injurious than cracks or openings, which, by being connected with the flues, admit cold air into the heated current, and thereby destroy, in a great measure, the effect intended. To the practical man who is aiming at eminence in his profession, we cannot too much enforce these observations, as they have been practically proved to be of the greatest importance.

Before concluding these observations upon the construction of this class of fire-place, we wish most strenuously to impress upon our practical readers the mistaken and false economy of making fire-grates too small, a practice that most completely defeats the principal object in view, namely, that of saving fuel.

A very little reflection will clearly show that where the space for fuel is too small, the want of room to spread the fuel will cause it to lay in such a compact and solid state, that the gaseous parts will be distilled and pass along the flue without being ignited, and by such means, instead of imparting heat by entering into combustion, a precisely contrary effect will be produced. And if, on the other hand, very small portions of fuel are frequently supplied, the opening of the door of the fire-place so repeatedly will permit so much cold air to enter as to essentially diminish the heating of the vessel, and its contents, independently of the great loss of time that will be required to keep up a steady heat.

There is also another circumstance of great importance, which must be admitted into the consideration of this subject, namely, that where fire-places are made sufficiently large, fuel of a much coarser description can be used, and a very equable and economical heat may be produced; for, in such cases, the cinders and ashes from the common fire-grates, when mixed with a due proportion of small coals, will be not only sufficient for creating a proper heat, but will not require half the attendance that pure coals with a pinched fire-place will do.

We have been induced to impress these observations, from a perfect conviction of their practical utility, having frequently observed the great loss that accrues, and serious inconvenience that is sustained by many families who have employed persons to set the ordinary kitchen-copper, which is too frequently executed upon such bad principles, that a great portion of the advantages and convenience of that very useful apparatus is lost to the public. The length of the bars, in most cases, should be about three-fourths of the diameter of the bottom of the boiler, and if they are loose bars, they will be much better than a frame cast with all the bars entire, the space between each bar should be about half an inch. And it should be remembered that the flues of these kind of fire-places are as likely as others to be clogged with soot, and therefore it will be very requisite to have loose bricks, or stoppers, placed in proper situations, as shewn at *c*, *fig.* 2, which will give great facility in cleansing such flues, and frequently prevent danger from fire in buildings where they may be erected.

It may be necessary to state, that the same precautions and directions ought to be observed in *figures* 3, 4, and 5, as in *figures* 1 and 2. *Figures* 3 and 4 represent a section and plan of a hot-plate, which is most generally of cast-iron, resting about an inch on the brick-work all round, and a rim of wrought-iron should be fixed round the external brick-work, to protect it from being broken or otherwise damaged. The bridge of fire-brick ought to be built to within three-quarters of an inch of the plate, leaving that distance between the bridge and the under-part of the plate, for the smoke and heat to pass on the way to the chimney.

The dotted lines, in *fig.* 3, shows the position of the flue and the chimney; *fig.* 5 is the plan of the copper-boiler, with the bottom part contracted round the grate. The smoke rises at the opening in the back, passes round the bottom, and then enters the chimney.

Fig. 6, is the representation of a charcoal-stove, which is composed of solid brick-work, except it should so happen that a very large one should be wanted, then the wall may be built hollow and filled up with rubble. The grates are constructed of cast-iron, and placed four inches deep, with a vacuity under to the floor for the ashes to drop, and thence they may be drawn out through the cavity left in the front.

Stoves of this description are used for stew-pans, chafing-dishes, &c. A rim of wrought-iron should also be fixed round the brick-work at the top, about 3½ inches deep. The grates are of different sizes, according to the magnitude of the building.

On the Method of fixing a Copper-Boiler for Brewing.

302. *Fig.* 1, *plate* XXXV. is a section through the upper vertical line in the middle of the copper; *fig.* 2, a horizontal section of the copper taken under the bottom, and may be considered as the plan of the brick-work immediately above the grate. This method offers the least obstruction for the flame to play on both sides of the grate, where it meets on the opposite side of the prop at A, and thence rises in a sloping direction towards the back, which is shown by another section, *fig.* 3; the part at A, being the partition, as shown on the plan, *fig.* 2. Above the partition, A, the whole of the smoke rushes into a chimney or tube, ascending up the back of the brick-work, and is discharged into the atmosphere at the top. This chimney is shown in the section, *fig.* 3, which is taken at right-angles to *fig.* 2, as exhibited by the plan, *fig.* 4, which is the plan of the section, *fig.* 3.

Fig. 5, is a vertical section taken through the axis of the boiler, and through the discharging cock, B and C, shown on the plans. *Figures* 2 and 4 are two other props, besides the partition A, which is also used as a prop. The plan or horizontal section, *fig.* 2, is that of *fig.* 1, and the plan or horizontal section, *fig.* 4, is that of the vertical section, *fig.* 3; *fig.* 4, being the same as *fig.* 2, only differing in its position, which is *fig.* 2, turned at right-angles.

Fig. 6, is an elevation of the front, showing the fire-place, and the manner of suspending the door by means of pullies, which is balanced by a weight depending from the remote pulley. The top of the brick-casing round the copper is entirely closed round the circumference, as shown on the three sections at *aa, aa,* &c. There is a similar ring of brick-work which encompasses the circumference of the copper, and is also shown on these sections, at *bb, bb,* &c.

This construction is that recommended by Mr. David Booth, a gentleman well known by his numerous publications, and his scientific acquirements on practical and useful subjects.

We cannot conclude this department of instructions without again enforcing upon our scientific friends the absolute necessity of making the atmospheric air pass through the ignited fuel, and also to take especial care that their work may be made so close and sound as to prevent a circulation of that which is very properly called the pabulum of life and flame; for one fact should never be lost sight of for an instant, namely, that whatever air is admitted, without being decomposed or used up by the fuel, must of course tend to impart its own temperature to the surrounding objects, and, consequently, rather retard than accelerate the object in view. We are well aware, that however well fire-places of this kind may be constructed, much evil is frequently produced by having to join the flue, or carry it into one already formed. In such case, it will generally be well to continue the flue belonging to the boiler fire-place to as great an extent as possible, before it enters the flue already formed, which will assist, in some degree, to obviate a portion of the difficulty; and where only one of the fire-places is used at the same time, that portion of the flue that leads from the one not in use, should be stopped, to prevent the entrance of air through it at such part.

CHAPTER VIII.

SETTING RETORTS, AS PARTICULARLY APPLICABLE TO GAS-WORKS.

303. As Gas, for the purpose of affording light, has now become an article of general utility, it may be necessary to give some account of the brick-work, particularly of that very essential part of it, which applies to the setting of the retorts.

Notwithstanding the numerous experiments made, at the principal gas-stations, as to the best shape, and the most economical method of setting retorts, for the purpose of carbonizing coal, yet very little improvement, generally speaking, has been made, in either of these most important points, since the first introduction of gas-light.

Retorts made of cast-iron; lumps or tiles, made of fire-clay, have been tried; and ovens built entirely of fire-bricks, have also been used, with greater or less success. Of these materials, we may merely notice generally, that metal, being an absorbent of heat, and clay a *non-absorbent*, it hence follows, reasoning *à priori*, that the former would appear to be decidedly the preferable material for retorts. The practice at the principal gas-works sanctions this opinion. Indeed, metal retorts are now almost universally used.

Retorts have been tried of various shapes: cylindrical, oval, semi-circular (or D shaped), parallelopipedal, &c. The form now most generally adopted is cylindrical, 7 feet 6 inches long, and 12 inches internal diameter. But whether that shape be the most profitable to the gas-manufacturer, can only be ascertained by actual experience; the results of experiments being so various, as regards gas matters, in different hands, no certain conclusion can with safety be drawn from them. The only sure criterion therefore to judge by is from making *a fair* trial.

The modes of setting retorts are as multifarious as their shapes. They were first set on what is termed the flue-plan: sometimes one, two, three, and four retorts were set to one fire, which was placed either in front or at the back of the retorts, as room permitted, or as the fancy of the engineer directed. Sometimes two fires were used to heat a bench of three or four retorts. These flues were carried over and under the retorts repeatedly; and were certainly well calculated to produce an equal distribution of heat throughout the retorts. Mr. Peckston states, that two retorts, set on the flue-plan, to one fire, carbonized at 20 per cent. for fuel only. He does not, however, state directly the quantity of gas produced by this plan, from a chaldron of coals; but, from the results given by him, of the produce of different kinds of retorts, in a Table, p. 141 of his book on Gas Lighting, we conclude it to have been 10,000 cubic feet, per chaldron, of Bewick and Craster's Walls-end coals.

Retorts, for the destructive distillation of coal, were next set on what is designated the *oven-plan*. This was the design of Mr. A. Rackhouse. His first experiment was made at one of the gas-works in London, by heating one retort in an oven. It was reported to heat very uniformly, and at little expence. He next set two in one oven, then three, afterwards five, and, lastly, seven. It is proper to observe, that cylindrical metal retorts, set in benches of five retorts each, on the oven-plan, to one fire, is *still*, by far, the most general mode adopted at the best conducted gas-light establishments.

Mr. Stone, engineer to the Ratcliffe Gas Company, took out a patent some years ago for heating retorts by means of a coke-oven. This is still used at Ratcliffe works; and answers the purpose admirably. There it has the peculiar advantage of being managed under his own immediate inspection. It has failed in other hands, but from what cause is not at present very clearly understood. At Ratcliffe it has proved successful; and, having examined it carefully, we are far from experiencing any degree of surprise that it should be so. The coke made by this oven is excellently adapted for the blast-furnaces of founderies; and sells for from 30*s*. to 32*s*. per chaldron. One oven heats seven square or parallelopipedal retorts, 6 feet 6 inches long, (they purpose making them a foot longer, which will be a decided improvement,) by two feet broad, and one foot deep, internal diameter. The oven is charged every thirty hours; and the retorts every four hours.

The grand object in view, in setting retorts, and in choosing the best configuration of them, is to be enabled thereby to make the greatest quantity of the best carburetted hydrogen-gas, at the smallest expence, and in the shortest space of time.

In order to be able to accomplish this, there are four cardinal points which demand particular attention: 1st, To use as little fuel as possible, in bringing the retorts to a proper degree of heat, and in keeping it up; 2d, To distribute and equalize that heat throughout the whole body of the retorts; 3dly, To protect the retorts from the immediate action of the fire, without prejudice to the economizing of fuel; and 4thly, To dispose of the coal, within the retorts, so as to produce an abundance of good coke and carburetted hydrogen gas, of a sufficient specific gravity and illuminating power.

It may, perhaps, be sufficient for all practical purposes, to give, in the first place, a description of the mode, as presently practised at the principal gas-works, of setting cylindrical metal retorts, in benches of five retorts, to one fire, on the oven-plan; next a description of Mr. Stone's coke-oven, which is capable of heating seven parallelopipedal retorts, as now in action at the Ratcliffe gas-works; and, lastly, an improved method of setting five retorts, in one oven, to one fire. By attending to these several modes, any number of retorts may be set on the same principles.

Before entering on this, it may be proper, however, to explain why five retorts in a bench are preferred to seven. The fact is, the heat is much more easily distributed amongst five than seven retorts. It is *no saving of fuel* to use seven retorts in an oven, heated by one fire. The con-

nection-pipes of the two undermost retorts, namely, those placed at each side of the furnace, are, from their shape, easily choked up; and, while one side of these lateral retorts is exposed to an intense heat, the other side is comparatively cool: the consequence is, that the side thus exposed gives way, in a very short space of time, rendering these retorts totally useless, while the same extent of fuel must necessarily be continued to the remaining five, which was necessary to heat the seven, instead of that limited quantity of fuel, for which the furnaces to benches of five retorts are adapted. Indeed, there are some intelligent practical men, who, from motives of pure economy, and in order to distribute the heat equally, recommend, in benches of even three retorts, to use two small well-regulated furnaces under them.

Bench of Five Retorts.

304. *Figure* 1, *plate* XXXVI, is a front view of a Bench of five cylindrical metal Retorts, A, A, A, A, A, set on the oven-plan, in a finished state. One of the undermost row of retorts is shown with its lid on, and secured by means of an iron strap and screw, *fig.* 5. The eyes of the lid in *fig.* 4, fit on the straps, S, *fig.* 6, and the lid is then tightened by means of the screw, *fig.* 5. (*Figures* 4, 5, 6, are drawn a larger size to show this operation more distinctly.) The centre retort has its lid on merely, but not secured, as above described. The others are shown without their lids. For larger works, the beds of the retort-benches are generally supported by an arch of brick-work, marked B, *fig.* 1. It is a sunk floor, 7 feet deep, with a passage to it, for a wheel-barrow, by an inclined plane. In front of the whole row of retort-benches is a floor of iron-plates, supported by iron bearers, as shown at *fig.* 3. In this floor there are hatchways, or trap-doors, as at C, C, C, *figures* 1, 2, and 3, for the purpose of allowing the red-hot coke, when drawn from the retorts, to fall into the sunk-floor. The iron floor, or stage, as it is sometimes called, is made broad enough to admit of scrapers, and other tools, necessary to be used by the stokers, the whole length of the retorts. *a*, (*fig.* 1,) is the door of the fire-place; *b*, of the ash-pit. The ash-pit doors are furnished with perpendicular slits of about two-thirds their length, and five or six-eighths of an inch broad, for allowing a current of air to pass to the fires. The dimensions of these slits can be decreased by another piece, made with corresponding openings, which piece is made to slide horizontally in grooves, in a line with the openings in the door, so as to regulate the admission of air to such a degree as may be necessary. *c*, *c*, *c*, *c*, *c*, are the pipes which convey the gas, as it is evolved from the retorts, to the hydraulic main E; *d*, *d*, *d*, *d*, *d*, are front views of what are termed the H pipes. P, *fig.* 3, *e*, *e*, *e*, *e*, *e*, *fig.* 1, are front views of the dip-pipes. F, *fig.* 1, is the pipe for conveying the gas, and other products evolved, towards their respective receptacles. G, G, G, cast-iron columns, fitted with crutches at the tops of the upper ones, for supporting the hydraulic main.

Figure 2, is a transverse section of the same bench of retorts, which supposes them to be cut through, from the top to the bottom, about the middle. In this section the dip and conducting-

pipes are not shown. A, A, A, A, A, the retorts; *a, a, a, a, a, a,* such parts of the arch of the oven and furnace as are constructed of the best Stourbridge fire-bricks, set in good grey-coloured Stourbridge fire-clay. In the next course, or that which is immediately contiguous to this, sometimes good Welsh or Windsor, or Newcastle, fire-bricks are used, set in Windsor fire-clay. The fire-bricks in the roof of the oven to be wedge-shaped, conformably to the radius of the circle, of which the oven is a segment. In order to keep the heat as close to the retorts as possible, the crown of the oven is flattened, by means of wedge-shaped Stourbridge fire-tiles, as shown at *b*. At the extreme end of the oven are two openings, which lead into the two small flues, *c, c*. These flues pass above the top of the oven towards the front of the retorts, and then each of them turn towards the centre flue, *d*, through which the smoke passes to the vertical flue, *e*; and from it into the main flue, H. *f*, *fig. 2*, is the fire-place, and *g* the ash-pit, *h, h, h,* are fire-lumps placed below the lowermost retorts, to protect them from the immediate or too intense action of the fire. The two upper retorts were formerly supported near their middle by wrought-iron belts, which were brought through the upper part of the oven, and passing through a cast-iron bearing-bar, placed above it, were secured by means of nuts in the situation wanted. From the great expansion of the iron straps, by the influence of the heat, &c., fire-bricks and fire-tiles, supported (as represented in *fig. 2*,) on the undermost course of fire-guards, with occasional openings between them, are now most generally adopted.

When the oven-plan was first introduced, the retorts were supported by cast-iron props, bedded in the brick-work, crutch-shaped at top, and rising to a proper height to receive them. They are now universally abandoned, in works that are conducted on any thing approaching to scientific principles, and therefore not shown in the plate.

Figure 3, is a longitudinal section of the same retorts. A, A, are the retorts, the mouth-piece of the lower one being secured by the lid, *fig. 4*, and cross-piece, *fig. 5*. The upper one is shown without the lid; *f*, is the fire-place, with the position of the grate-bars. These are made deep in the centre, and chamfered off, so as to admit the air freely. *g*, is the ash-pit; *o, o, o, o,* are the openings, or, as they are termed, the pigeon-holes, from the furnace to the retort oven. S, the fire-lumps: these are made generally 16 or 18 inches long, and sufficiently broad to cover the fire-place; they are from $2\frac{1}{2}$ to 3 inches thick, of the best Stourbridge fire-clay. W, W, the fire-guards; *h* is the conducting pipe which conveys the gaseous and other products from the retorts to the H pipe, *i*, and that carries them into the dip-pipe, *k*, which enters into the hydraulic main, E. C is the opening, or trap-door, in the iron floor, for allowing the red-hot coke, as drawn from the retorts, to fall into the sunk floor, X. In *fig. 1*, R represents a cast-iron binder, to prevent the brick-work from being disturbed by means of the great heat in the ovens. To these binders flat straps of wrought-iron are attached; they pass considerably into the brick-work, so as to take a sufficient hold of it. It is not considered necessary for the binders to extend to the sunk floor, as here represented: it is sufficient, generally, that they commence four inches from the plate-iron floor, and reach

to within four inches of the top of the benches. Two of them are placed at the extreme ends of the row of benches, with a flat piece of wrought-iron between them; and one binder is placed between each bench of retorts. Sometimes these binders serve to secure a large cast-iron plate, (with holes in it for the retorts to pass through,) used for the purpose of preventing the walls of the retort-benches from protruding, by means of the excessive heat. It is an excellent plan, though somewhat expensive at starting. These plates are placed on both sides of the benches, where the mouths of the retorts are at one side of the benches, and the furnace-doors at the other: an arrangement which certainly requires a capacious retort-house; but, by which, the health and comfort of the stokers are considerably benefited.

Fire-Bricks, &c.

305. Fire-bricks, fire-guards, tiles, lumps, &c., are made of fire-clay, or, what is termed by brick-makers, from its property of infusibility, "*refractory clay.*" It consists of alumine, (the basis of all clays,) and silica, in variable proportions: or of alumine and lime. Either of these, in any proportions whatever, are infusible, by the strongest heat that can be raised in our furnaces: hence they are used for making fire-bricks, crucibles, and glass-house pots, &c But it must be particularly remarked, that a mixture of alumine, *lime*, and silica, is very fusible; and the fusion is most readily effected when two parts of silica to one of lime is employed. Oxide of iron also renders clay fusible: but not unless its proportion be much greater than is ever likely to occur in any clay used for the manufacture of bricks. Those clays that contain much feldspar, as is generally the case in most clays that are used for making common bricks, are likewise easily fused. Fire-clay most commonly forms a portion of that class of stratified depositions called by Geologists the "*coal formation.*" It is often much blackened by coaly matter, in which case it is to be considered as rather of an inferior quality. The best is, therefore, of a light bluish grey colour, such as is to be found at *Stourbridge*. This is certainly the best fire-clay in England. In making fire-bricks, &c., the clay is mixed up with powdered crucibles, or old fire-bricks, or glass-house pots, in place of the sand generally used in the manufacture of common bricks. It does not communicate the tendency to fusion, when in contact with various fluxes, that is communicated by silicious sand. The clay is first ground, and then any pieces of iron-stone, &c., that may be still remaining in it, must be separated by sifting it.

Coke Oven Plan.

306. *Figure 7, plate* XXXVI, is a transverse section of one of Mr. Stone's coke-ovens, as used at Ratcliffe Gas-works, for heating seven coal-gas retorts, of the dimensions already described. O is the oven, 11 feet long, $2\frac{1}{2}$ feet deep, and in breadth, according to the length of the retorts to be heated. At present, it is only 6 feet 6 inches broad. A, A, A, A, A, A, A, are the seven

retorts; four in the undermost row, and three in the upper row: each of these rest on two of the under row; *g* an arch, of a very flat elliptical form, above the oven, which is made of the best Stourbridge ground-edged fire-bricks. It is brought to a level at the top, that the retorts may all lie in one horizontal line; *p, p,* are the flues from the oven to the retorts. There are six of them, three on each side; *a, a,* is an arch, formed of the best fire-bricks, above the retorts; and *b* is the flattened crown of it, to keep the heat as near the retorts as possible. The flame, as in *fig.* 2, passes through the two small flues, *c, c.* These, passing above the top of the arch, towards the *back* of the retorts, (not the *front,* as in *fig.* 2,) each of them turns towards the centre flue *d,* through which the smoke passes to the vertical flue, *e,* and lastly, into the main flue, H. *s, s, s, s, s,* are the fire-tiles in the bottom and sides of the oven, &c.

Figure 8 is a longitudinal section of the same seven parallelopipedal retorts. The same letters denote the same parts as in *fig.* 7. P, P, P, is the ground line, F is the sunk floor, at the side where the mouth, D, of the oven is placed. The mouth-pieces of the retorts are at the opposite side; L, L, represent the cast-iron binders, described with the bench of five retorts, to prevent the walls from bursting by the excess of heat. O is the coke-oven; *g* the flat arch roof; *p, p, p,* three of the six flues; *s, s, s, s, s,* the fire-tiles; *a,* the roof of fire-bricks above the retorts; A, A, the retorts; *c, d, e,* H, the flues already fully described; *h,* is the connection-pipe, leading from the mouth-pieces of the retorts to the hydraulic main, already fully shown in *fig.* 3. The other parts will be sufficiently understood by a reference to *figures* 1, 2, and 3.

Improved Method of setting Five Retorts in an Oven.

307. *Figure* 9, *plate* XXXVI, is a transverse section of an improved method of setting five coal-gas retorts, A, A, A, A, A, in an oven, to one fire. The retort immediately over the fire is set precisely in the same manner as represented in *fig.* 2: but the two side retorts, and the two upper ones, are placed on what is called saddles (fire-tiles of the shape represented in *fig.* 10). These saddles, for the upper retorts, are 15 inches wide, from *a* to *b,* 14 inches from *b* to *c*; and from $2\frac{1}{2}$ to 3 inches thick, of the best Stourbridge fire-clay. From *b* to *c,* is $4\frac{1}{2}$ inches; from *c* to *d,* 5 inches. The versed sine of this segment is 2 inches. From *d* to *e* is $4\frac{1}{2}$ inches. They are rebated or checked, so as to overlap each other at their joinings, at the ends, *a, b,* and *k, c.* From *h* to *f* is 11 inches. The openings in the saddles are, of course, meant to correspond with the side-flues and interstices below them. Throughout the whole length of the oven, the openings *s, s, fig.* 9, under the centre part of these saddles, traverse the piers that divide the side-flues, or, as they are generally termed, the pigeon-holes: (those openings that run from each side of the furnace to the outer sides of the lateral retorts.) This admits of a full and free circulation of the heat, which is indeed the great object in view

throughout the whole of the plan. The saddles placed under the two upper retorts are chamfered off at the edges, so as to fit the shape of the undermost retorts. Above the saddles, the usual fire-guards are placed, care being at all times taken that these guards join, or break joint, either on *b, c,* of the saddles, or on *d, e.*

Instead of the flues, *c, c,* as in *fig.* 2, entering only at the back end, and thereby causing a draught to that point,—highly injurious to the retorts,—there are two rows of several openings into the flues *d, fig.* 9, throughout the whole length of the oven; and, in place of uniting in one flue, *d,* as in *fig.* 2, and going to the back part of the oven *above* the flues *c, c,* the flame from *c, c, descends* in *d,* until it arrives at *e, e,* (half-way nearly down the sides of the oven,) through which it passes to the vertical flues H, H, and thence into the main flue K, keeping the heat all the while as near to the body of the retorts as possible; and counteracting, at the same time, any injurious draught to one part of the oven more than to another. The heat, by this means, is kept nearly as much towards the front of the oven as towards the back of it. Indeed, so much has this been the case, that the engineer, not anticipating a result so very successful, found that, notwithstanding the great precautions he had taken, to brace the front wall with binders, &c., they were totally inadequate to resist the very great expansion of the brick-work, *in front,* caused of course by the quantity of heat now brought so much towards the front of the retorts. When these retorts are once brought to their proper degree of heat, very little fuel is afterwards required to keep them at work. But the saving in fuel does not stop here. In three benches, set on this plan, the centre bench has consumed the whole of the smoke of the other two benches, while they, at the same time, were kept up to a proper degree of working heat. Suppose *figure* 9, to be one of three-benches of retorts, placed on one side of the centre bench, *fig.* 11. (If there be a series of them, every three benches must have an independent flue, so as to open occasionally either into the main flue, or under the grate of a centre bench (by means of dampers) through a flue similar to *n, o.*) Passing in a thin stratum, of 18 or 20 inches by 3 deep, under the furnace-bars of the centre bench, *fig.* 11, the smoke is thereby kept hot, which is essential to be attended to; and, in the ash-pit of *fig.* 11, receives as much of the oxygen of the air as renders it again combustible. In this state it passes upwards at P, P, through the interstices of the bars, and is consumed by the fire of the centre furnace: answering every purpose, in fact, of so much fresh coal. Fuel is thus not only saved, but a great nuisance to the neighbourhood very much diminished. The method of shutting off communications, by means of dampers, is an operation of such extreme simplicity, that it must be unnecessary to describe this part of the process. In *fig.* 9, the ash-pit is sunk a little below the floor, R. This enables the stokers to charge and draw the upper tier of retorts more easily; and is not attended with any obstruction whatever to the free draught of air to the furnaces.

Of the saddles, *fig.* 10, five are required for each circular retort: the retort being 7 feet 6 inches long, by 14¼ inches external diameter.

The saddles for the under retorts are of the following dimensions:—From *a* to *b*, 17¼ inches; from *h* to *f*, 7¼ inches, and the ersed sine of the segment *c*, *d*, 5 inches. The other parts, in all respects, are similar to those for the upper row of retorts, as already described.

Figure 12 is a transverse section of the fire-guards, and *fig.* 13 a plan of them. Five pairs, or 10 pieces, are required for each circular retort of the above dimensions. They are rebated in the under ends, to over-lap. At *a*, *fig.* 12, the edge is 1½ inch thick: at *b* it is only three-quarters of an inch thick. From *a* to *c* the tile is 9½ inches broad: from *d* to *b* it is 8 inches: from *c* to *f* is 14 inches. The space from *c* to *d* may be made to suit any diameter by being filled up with fire-clay. Here the tile tapers down to one inch in thickness. At least half an inch of space should be left for the retorts to expand. On account of the expansion of the metal of the retorts, these guards are much better in two pieces than in one. These, *fig.* 12 and 13, and saddles, *fig.* 10, are, it will be seen, drawn to a much larger scale than the other figures in this plate.

Safety Plugs, &c.

308. There is a circumstance, intimately connected with coal-gas retorts, which we may here notice, as it cannot be considered altogether irrelevant to our present subject. The retorts, when heated, expand of course in all directions, and contract in cooling. Those set five in a bench, as we have described under the head of "Improved Method of setting Five Retorts in an Oven," have been observed to expand towards the front of the bench, where the mouth-pieces and connections are placed, protruding as much as five-eighths of an inch beyond the brick-work of the bench. Now, according to the present mode of jointing the connection-pipes, which connect the retorts with the hydraulic main, these connection-pipes must be fractured and injured by this protrusion, if they do not yield to it; and it is well known that neither cast-iron, nor the joints commonly made on it, with rust cement and bolts, can yield by any means, with safety, to this extent. It is true that, if *all* the retorts joined to the hydraulic main were in action, at the same time, and the expansion affecting them equally, their united expanding force might, in such a case, have the effect perhaps of *turning the hydraulic main outwards*, were it at all moveable on its supports; and thereby preventing any fracture in the connection-pipes or their joints, by thus yielding to their thrust. But when it is considered that, from various causes, which need not be here enumerated, there is at all times on an average, in gas works of any magnitude, at least one bench of retorts in six *out of action*, and attached to the same main, it will be evident that the remedy we have alluded to *cannot, at all times, be relied on.* In the generality of *oil-gas* works, however, this expansion of the retorts is provided for, by a very simple and effectual contrivance:—On the vertical connection-pipe, not very far distant from the retort, an hydraulic joint is formed, which is filled with fusible metal instead of water. This metal is composed of eight parts of bismuth, three of tin, and five of lead, with a very small portion of mercury (about an ounce to a pound of the whole of the other materials). This composition

(which is well known by the name of Sir Isaac Newton's metal) melts at the temperature of 197° of Fahrenheit, without any sensible evaporation, effectually sealing the hydraulic joint, as the heat arrives towards the point just mentioned; and allowing a sufficiency of play to permit the retort either to expand or to contract. Indeed, where no safety-plug is used, it also acts as a safety-valve, in case of any obstruction happening, as is often the case, between the retorts and the hydraulic main. But, in the most approved modern works, safety-plugs are generally used. They not only serve the purpose of affording safety to the works, but they enable the gas-maker to discharge the crude and watery vapours from the coal, which are evolved in great abundance on its first exposure to the heat of the retorts; and, towards the latter end of the charge, (should it not be convenient to *draw* the retorts at the proper time,) they likewise enable the stoker to discharge the sulphurated hydrogen, azotic gas, hydrogen gas, &c., evolved by the coal, *if allowed to remain, beyond the proper period, in the retorts;* and which impurities, but for these plugs, or other contrivances of a similar description, find their way (under the circumstances just stated), to a certain extent, into the gasometer, and deteriorate the gas accordingly. They also very unnecessarily and injuriously saturate the purifying mixture, rendering it too soon inefficient. By lifting these plugs, during the operation of charging or drawing the retorts, another important advantage is obtained: much of that intolerable heat and smoke, issuing from the mouth of the retorts, and to which the stoker was exposed, is now very considerably diminished, by their thus allowing the flame and smoke to ascend through the vertical connection-pipes, instead of issuing out, as heretofore, in suffocating volumes directly in his face.

In the case, too, of any choking up of the connection-pipes, the stoker has *merely to lift the safety-plugs*, and clear out the pipes, by introducing a rod of iron into them, without any of that delay whatever which must have taken place to *unscrew* and remove the *glans*, that were formerly used, at the upper extremities of the connection-pipes. During the tedious operation of unscrewing and taking off those caps and glans, frequent burstings and explosions have taken place in gas works, as might have been expected, from the excessive concentration or compression of the obstructed gas. A compression of gas, exceeding the weight of the plug, will lift it up, allowing the compressed gas to escape; and this escape will, consequently, be more or less as the compressed gas has the effect of raising the plug. It is on precisely the same principle as the safety-valve of a steam-boiler.

Retort Furnaces.

309. We may remark that, by keeping the heat much more towards the front of the retorts, than it is kept by the common method we have described of setting retorts, and which causes a partial and injurious draft to the back part of the furnace only, the furnace-doors are much more, of course, exposed to injury than formerly. This is to be guarded against, 1st, by fixing fire-tiles, wedged

with chips and fire-clay on the inside of the doors; and, secondly, by having a few spare doors at hand to substitute for any that may be over-heated, as will be the case, notwithstanding the precaution of lining them with fire-tiles. In order to be able to do this with facility, however, the doors should be so hung as to be readily lifted off and on. A spare door for each furnace is by no means necessary: one to three or four furnaces will be sufficient. The first taken off will be gradually cooled, so as to be put on again in five or six minutes thereafter. Between the furnace-door and the grate-bars, a plate of cast metal is placed, to prevent the brick-work from being injured by the action of the rake, or shovel, &c. It is about half an inch thick of metal, and from 10 to 12 inches broad. The grate-bars rest easily on cross-bars of cast-iron, 4 inches square, placed at each end of the furnace in the usual way. These cross-bars have a rabbet in them, to receive the ends of the grate-bars, so as to allow both of their upper sides to be flush with each other. The grate-bars should be much deeper at the centre than at the ends, (say 4½ inches at the centre, and 2½ at the ends,) and chamfered off, so as to admit the air freely. Their distance from each other should not be less than six or seven-tenths of an inch. As they heat, this opening will diminish by their expansion. Their average length, for gas retort-furnaces, is about 42 inches.

Three large fire-lumps are generally used in each furnace. They are placed at the extreme back; one is laid transversely, at the end, and the others join it longitudinally, one at each side. This is to oppose the excessive action of the fire at that part of the furnace. Their dimensions are: for the two side lumps, 2 feet long by 9 inches deep, and 6 inches thick; and for that at the back, 18 inches long by 9 inches deep, and 6 inches thick. They are cut off at the upper sides, to a certain extent, so as to communicate readily and correspond with the side-flues, or pigeon-holes, as they are termed by the workmen. The lumps are rabbeted together, and joined by fire-clay in the usual manner. The rest of the furnace is built of fire-bricks, and corballed at the upper part, for 3 or 4 inches of projection, at each side. Twelve inches broad by 14 inches deep, is a very general size for a gas-work furnace, to heat five retorts set on the oven-plan. If the retorts be 7 feet 6 inches long, the horizontal line from the front of the furnace or door will be 66 inches. This includes the plate already mentioned, 12 inches; the length of the grate-bars 42 inches, and 12 inches more, of horizontal space. After this, the back of the furnace should rise in a gradual sloping direction, terminating within 10 or 11 inches of the end of the retorts. This affords considerable protection to the ends of the retorts; and, if they are skilfully set, no apprehension whatever need be entertained of that part of the retort not being sufficiently heated. From the grate-bars, to its junction with the retorts, the bottom of the furnace must be laid with Stourbridge fire-tiles, of from 2½ to 3 inches thick. It will be seen, by examining the *saddles*, *fig.* 10, *plate* XXXVI, that the side-flues in the furnace are placed 9 inches apart, and are 5 inches wide. The practical advantages of such an arrangement, an experienced bricklayer will be at no loss to appreciate.

Chimney.

310. In erecting the chimney, or *stack*, to the furnaces, the first point to be attended to is the foundation.

For the other purposes of a gas work, it so happens that a shaft or well will be required to be sunk. This will afford the means also of ascertaining the substrata. Chimnies for gas works are made generally much higher than is absolutely requisite to afford the necessary draught. That is commonly done for the purpose of carrying off the smoke more effectually from the neighbourhood; otherwise, a chimney of from 40 to 50 feet high, is all that would be required for the mere purpose of draught. For an air-furnace, a chimney of 40 feet, for example, in an open situation, is considered abundantly sufficient. The area of the flue must of course be in proportion to the volume of smoke that would issue through it, were the whole benches connected with it, in action at one and the same time

If the foundation be of a firm and rocky nature, all that is required, of course will be to bring it to a proper level. Two scarcements only, of 4 inches each, will be quite sufficient to commence the chimney. If of compact gravel or chalk, 2 feet below the surface may be dug to found on, and the breadth of the foundation should be as three is to two of the wall. If of clay, the breadth of the foundation, in proportion to the upper walls, should be about double, and sunk at least 4 feet. This depth is particularly necessary, if the substratum be of clay: for in clayey ground the effect of shrinkage, by heat, is often sensible at that depth below the surface. In boggy earths, or infirm sand, or alluvial deposit, piling and frame-work may be necessary. No mortar should, however, be used with the piles, as it rots the wood. On this account, to cramp the under courses with *cast-iron*, and only compact clay used instead of lime, has been recommended. If the foundation be dry sand, it will require to be double the breadth of the chimney, as in a clayey soil; but only 2 feet of depth will be required, being a sufficient protection against the effects of frost, which has seldom been known in this country to exceed that depth of dry loose sand. But the extent to which all these precautions require to be carried, will depend on the height to which it may be thought necessary to carry the chimney, as well as on the nature of the inferior strata. The foundation-walls should diminish on each side gradually from the bottom towards the surface of the ground. These diminutions are termed scarcements. If large flat stones can be readily got, they form by far the best foundations. Every course, whether of brick or of stone, should be well grouted with hot mortar; and great care should be taken, in the case of stones being used, not to *roll them* on the courses already laid, as is sometimes done by careless workmen, but to deposit them at once in their proper beds, by means of a triangle, or other means, and they ought not to be afterwards shifted: or, if shifting should be unavoidable, the same precautions must be used in doing so, and also in replacing them.

After the foundation has been brought to the surface of the ground, we shall suppose that a chimney of 120 feet in height is required, with a flue of 4 feet square at top. The last basement course should be 12 feet 8 inches square. The previous courses having been regulated, as to their breadths and depths, by the several circumstances and localities above enumerated. Then, with a scarcement of 4 inches, the walls of brick-work should commence 3 feet thick, with a flue of 6 feet, and contracting at every 20 feet, as under, the chimney will terminate with a flue of 4 feet, and 9-inch wall at top; viz.—

	Ft.	Bricks.			Ft.	In.
1st,	20	4	or		3	0
2d,	20	3½	—		2	9
3d,	20	3	—		2	4
4th,	20	2	—		1	6
5th,	20	1½	—		1	2
6th,	20	1	—		0	9

A light ornamental coping of cast-iron is sometimes used with advantage. But bricks carefully cemented, or a coping of stone, clamped together, will answer the purpose equally well. There is no utility, in so far as the draught is concerned, in contracting the flue at the top. Indeed, the area of the flue *at the top* ought to be equal to the greatest volume of smoke that may be ever expected to pass through it: the contraction being merely for the purpose of saving materials at the bottom.

For a chimney of 60 feet in height, to start with 7 feet square at base, and a wall of 18 inches, with a flue of 4 feet, and terminating with 3 feet 6 inches square, and flue of 2 feet at top, is a very good and safe proportion: provided two feet of a flue at top is considered to be adequate to the free escape of the smoke.

From the point of communication with the flue from the furnaces, to the height of from 15 to 20 feet, according to circumstances, it is proper to line the flue with fire-bricks 4½ inches thick. Between this course, and likewise the remainder of the interior course (to within 10 feet of the top) and the external wall, a space of nearly one inch should be left, or filled in with sand, to prevent the heat from injuring and cracking the outer courses. For the sake of strength, however, these courses may be occasionally bonded together, particularly towards the angles. Although the upper part of the interior course of bricks in the chimney need not be of fire-bricks, as that nearest the flue of the furnaces, yet the bricks ought to be of the best quality hard-stocks, and set also in fire-clay.

A great and most unnecessary expense has, till lately, been incurred in providing exterior scaffolding for the erection of a chimney. By recent practice, however, this expense has been rendered totally unnecessary.

Spars are let into the interior course of the chimney, at the proper distances, for the men to mount up by, like the steps of a common ladder. The bricks and mortar are hoisted by a projecting beam and pulley at the end of it, to the top, where the bricklayers are at work; and when the work is finished, the spars, being merely wedged into their places with loose brick, are afterwards very easily disengaged. The spaces, in which they were fixed, are then carefully filled up with bricks and cement. By this simple method, a saving is effected of from £20. to £30. on the former method of outside scaffolding, in the erection of a chimney of only 50 or 60 feet high. It is quite safe and practicable for chimnies of any height.

It has been recommended, for the sake of accuracy, that only one bevelled plummet-rod should be used by all the bricklayers, in case of any discrepancies in the others, by which means one side might be run up in one direction, while the others are built in a different angle.

Brick chimnies are sometimes very sensibly to the eye off the true vertical line (perpendicular to the horizon), and yet stand safely in all weathers. There are some in Glasgow and Paisley of this description, that are at least 120 feet high. They have stood so for several years, notwithstanding the great rocking to which the upper part of brick chimnies are liable in high winds: the sines of their angles of inclination falling sufficiently within their bases, to preserve their equilibrium. They are still, by several degrees, more vertical than the celebrated Tower of Pisa.

CHAPTER IX.

ON FURNACES FOR THE FUSION OF METAL, &c.

311. The term Furnace is commonly applied either to vessels, or constructions, calculated by their form, and also the nature of their materials, to endure heats of very high temperature, and of long continuance. They are of first-rate importance in chemistry, metallurgy, and other branches of science connected therewith. They will be considered in this work under two distinct heads, namely, air or wind furnaces, and those usually called blast-furnaces. The air or wind furnace depends entirely for its supply of atmospheric air upon the draught produced by rarifying the column of air contained in the flues or chimnies of such structures; but in the blast-furnace, the supply of air is entirely produced by bellows of various kinds, or rather mechanical contrivances, which are used to force into the ignited fuel any requisite quantity of air that the various operations may demand.

It is much to be lamented, that in no work are those dimensions or proportions of the various parts of furnaces given that should enable us to determine the exact size that will be necessary for any given operation; but this will cease to be a subject of surprise, when it is considered that the various processes in chemistry, metallurgy, and other branches of science and art,

render it necessary that various proportions should be adopted, each of which may be applicable only to the purpose for which it is intended.

In cases of this description, we conceive the better plan is to give such general rules and directions as may lead a practical man to inquire, first, the nature of the effects intended to be produced; and, secondly, to make choice of and adopt such proportions as are best suited to the case required.

There is one well-established fact to which we particularly wish to call the attention of the reader, namely, that the heat generated by combustion must be greatest when the largest quantity of fuel is consumed in the smallest time; and also that, where fuel is supplied in sufficient quantity, and its quality good, the heat generated will likewise be in proportion to the oxygen consumed in its passage through the ignited fuel in a given time.

It should, at all times, be carefully ascertained what kind of fuel is intended to be used in a furnace previously to its construction, because some fuel contains properties that greatly assist in the process of combustion, while other sorts require the greatest aid from artificial and mechanical means to effect combustion in such a manner as to obtain a due degree of heat. All sorts of pit-coal contain a large proportion of gaseous matter, which is very readily decomposed with a comparatively slight degree of heat, and owing to its levity, it very rapidly ascends, and assists greatly in creating a draught, in which case atmospheric air will enter the grate, and passing through the fuel will, by its decomposition, assist the process of combustion; hence it will be seen that the gaseous parts of coal and other fuel, containing such products in large proportion, perform a very important part in the process of combustion. It is, however, found that pit-coal is a very inconvenient material for producing high degrees of temperature; for, as the gaseous parts ascend with great rapidity when heat is applied, they cause so quick a draught as to make a large portion of the atmospheric air pass through the furnace without coming in absolute contact with the coal, and hence, instead of heating the objects placed in the fire, they have a contrary tendency, by the introduction of such superfluous quantities of cold air. These remarks, it should be observed, apply exclusively to air or wind furnaces.

To avoid these inconveniences, and to obtain the most intense and lasting degrees of heat, when compared with the bulk of the fuel used, coke has been universally adopted, and this must ever be the case while pit-coal remains the principal fuel of this country.

On comparing the combustion of coal and coke, we shall find this manifest difference between the two. When coals are laid together in a furnace, or fire of any kind, a large quantity of tar or pitchy matter is liberated, which, running in between the interstices of the mass, has the effect of closing up a large portion of the passages through which it is necessary that air should pass and if, in this state, the mass be not broken or stirred, as it is commonly termed, the ignition of the whole will be very soon extinct, or combustion will go on in a very languid manner; but where coke is used, there being no tar and very little gaseous product to separate, the mass being nearly all pure carbon, the only visible change that takes place is a gradual

wasting of each piece exposed to the current of air necessary for its combustion, the ashes falling through the grate in very fine powder. There is, however, a property in coke that must not be lost sight of, and that is, the want of levity in any of the gaseous products that are decomposed or driven off from fuel of this description while in an ignited state.

The principal gaseous matters that escape during the combustion of coke are sulphurous and carbonic gases, which, mixed together, are specifically heavier than atmospheric air, and in order to make them ascend, and thereby create a draught, it is absolutely requisite that whatever air enters the furnace, should be made to pass completely through the fuel, where, after parting with its oxygen, it will be so rarified as to create such a draught by its rapid ascent, as to cause a continual supply of fresh air to the coke, and thereby obtain the greatest degree of heat that such fuel is capable of giving out.

As these principles are founded on facts, long established by practical experience, we cannot too much impress them upon the attention of our readers, because upon these principles depends the necessity of peculiar forms and constructions of various furnaces for particular purposes; for, upon the slightest reflection, it will easily be conceived, that if a furnace were constructed of a small area and considerable depth, where coal is to be the fuel, it would be quite impossible to carry on combustion advantageously, on account of the adhesive property of coal, when heated in the manner above described; but where coke, or even charcoal, is used, a much greater depth may be dispensed with, the fuel being of such a nature as to retain the interstices between each piece through which the air may pass freely, and thereby produce the beneficial effects above described.

It is entirely owing to these observations that the fire-grates or stoves for burning pit-coal have of late been so completely altered in form, the very deep fire-place being now completely rejected, and those of greater area and smaller depth being preferred; a practice perfectly consistent with reason, provided it be not carried to excess.

In regard to the velocity with which heated air ascends, it is as the difference of specific gravity between the atmosphere and the heated air. The principles upon which the motion arising from a change of a specific gravity depends, may be referred to the case of two weights hanging over a pulley. If they be of equal weight, no motion is produced, but if one be increased, or the other diminished, the heavy one will descend, and the light one ascend, with a velocity proportionate to their difference.

312. A very material part of every air or wind furnace is the flue or chimney, which, from considerable experience, we are enabled to say, should never be less than eighteen feet above the top of the fuel; but if thirty feet can be obtained, it will be much better, provided the area of such chimney be not too large. In general, it will be found advantageous to make the area of it equal, at least, to one-half of the furnace.

The height of the fire-place must be governed by the nature of the operations to be performed therein. If, for instance, it is to be used for melting metals of a very refractory kind,

the height must be such as to allow the fuel to lay about half the width of the furnace above the melting-pot, which should always be elevated upon either the fuel, or a suitable stand, at least one-fourth the breadth of the furnace above the fire-bars or grate, in order that it may be completely enveloped in the fuel; but where metals of more fusible qualities are to be melted, it will be sufficient to have the melting-pot imbedded in the fuel, without covering it to such a depth as is necessary in the case before mentioned.

The deeper the ash-pit or opening under the fire-grate of all sorts of wind or air furnaces can be, the better will they be supplied with atmospheric air; for it should be observed, that air is best supplied to the fuel when it enters perpendicularly, therefore, the greater the height can be, the more perfect will be the effect produced. It is for this reason that the most valuable and best constructed furnaces are supplied with air from a vault or cellar beneath, from which an ample supply of cool, and consequently condensed air, is always attainable. It is, indeed, owing to this circumstance, in a great degree, that the majority of the melting-furnaces, erected in vaults or cellars, are found to answer so well when compared with those which are placed in more elevated places.

313. A false economy has suggested the propriety of casting the bars of air-furnaces in one entire piece, forming a fixed and immoveable grate, but experience has proved that this is a bad method; for when the process of melting is completed, the whole of the ignited fuel must be lifted with tongs out of the furnace, which is attended with much difficulty; or, if this be not done, it must be suffered to burn out, which would be a very great waste of fuel, and also a very considerable loss. Another great inconvenience arises from the grate becoming in time covered with adhering clinkers or coal-slag, which can only be removed at the risk of breaking the bars in pieces, and, consequently, destroying the whole grate; but if wrought-iron bars of a proper kind be used, the whole may be removed in a very short time, by which means the fuel will be saved, and the bars may be cleaned without the least risk or injury. The precise form of some very improved bars we shall describe in another place.

Having extended our general observations on the principles necessary to be observed in the construction of air-furnaces, we shall now examine the nature of the materials necessary to resist the extreme degrees of heat that must be produced, in order to effect the objects required by the chemist, metallurgist, and philosophical experimentalist.

The materials of which the foundation or under part of furnaces is constructed may be of any kind that will bear the necessary weight; the principal attention of the builder should be directed to the quality of those that are to form the internal part or lining, where the greatest heat prevails, and also to the quality of the materials that are used, as cement, to unite the linings, and likewise the nature of the substances that are placed in immediate contact with the linings.

The best materials for lining the internal parts of furnaces are bricks or lumps formed of two-thirds of Stourbridge clay, beaten up and well tempered with one-third of the same mate-

rial, which has been submitted to a very great degree of heat, and by such means has become partially vitrified; or, in lieu of this, broken crucibles, after they have been used and rejected, will answer equally well. This compound must be used with as little water as possible, in which state it should be forced by great pressure into strong moulds that are capable of resisting the necessary compression of the materials, and in this state they should remain until, in drying, they shrink sufficiently to leave the mould without any force. They may then be laid out to dry very slowly, by which means they will be prevented from cracking, before they are submitted to the fire. When thoroughly dry, they should be burnt in any convenient kiln, when they will be ready for use. Lumps made in this way will be very nearly the same size when dry and burned as when they were in the mould, a circumstance that greatly ensures their soundness and durability.

Where Stourbridge clay cannot be obtained conveniently, or the lumps cannot be manufactured in the way above described, the common Welch lumps must then be used, but they cannot be so well depended upon in very high degrees of heat. The best material in which to set them, is a mixture of equal parts of Stourbridge clay and glass-grinders' slush. The slush is composed of fine sand, mixed with small particles of flint-glass, which is ground off from the various articles, during the process commonly called glass-cutting. These articles form an excellent cement, which is sufficiently tenacious to hold the parts together, and when great heat is applied, they partially vitrify, and thereby unite all the parts near the body of the fuel very firmly. Where slush cannot be obtained, fine sharp sand, free from any metallic oxyde, may be substituted, or what is better than either, where the expence can be afforded, namely, *flints* heated to whiteness, and then quenched in water, which process renders them so brittle, that they may be pounded in a mortar of iron, and passed through a coarse sieve; and if, when so prepared, they be mixed with Stourbridge clay, a cement will be formed that will resist almost any degree of temperature. Although this process may appear very troublesome, yet experience has proved that it will amply repay by its durability; and it must be remembered that it is only the lumps that form the lining near the body of the fire that need be united, or set with this cement, the parts behind, or in contact with these, may be sufficiently secured with good lime and sand.

It is an object of the greatest importance, in all works of this kind, to retain the heat, which is at all times generated at a considerable expence; for this purpose, therefore, it will be necessary to place in immediate contact with the internal lining, materials that are known to be non-conductors of heat; few substances will answer this purpose better than common place-bricks that are tolerably well burnt; in this state they answer the purpose exceedingly well, and more particularly, if the clay of which they are made be mixed with a considerable portion of charcoal, or coke-dust, the charcoal being a most perfect non-conductor of heat, and when enveloped in the clay, it will retain its properties for any length of time, provided the air be excluded. It will soon be found that a considerable saving in fuel will be effected, if these pre-

cautions be carefully attended to, and most of the operations will be more speedily performed from the same cause.

Where very intense heat is required to be kept up for a great length of time, some persons have adopted the method of forming the parts or lumps used for the lining so perfect, that they may be fitted into their places without any cement, or other material, to fix them together; by this means they may be more easily removed when destroyed by the action of the fire, and replaced without the aid of a bricklayer, or any part that is partially exposed to the greatest heat may be renewed without pulling down the principal part of the furnace. These will, by some persons, be considered advantages, but they are unfortunately attended by corresponding disadvantages, which will be found to arise purely from the joints being open, each of which will become a small flue, through which air will be passing instead of going through the fuel, and thus the want of solidity will be a very great evil, and, in some cases, will more than counterbalance any convenience or gain that may be anticipated.

There is no part of a furnace that requires more attention than the bars which form the fire-grate, for upon the proper shape and construction of these much of the success will depend, and as their preservation from decay is of considerable importance to every person that has to use them extensively, we shall now describe some as they are usually made, and then show how they may be constructed, so as to be much more durable, and equally if not more effective.

The usual cast-iron furnace-bars are of the shape shown in section at *fig.* 1, *plate* XXXVII; a side-view or elevation is shewn at *fig.* 2. These bars are made broad above, and tapering to their lower edge, having square blocks formed at each end of them to lodge upon bearing-bars. These blocks serve, when placed in close contact with each other, to keep the bars a proper distance asunder, and allow the air to pass freely between them to feed the fire.

The principal defects of these furnace-bars are, that they choke up, on account of the clinkers that form upon them, and that they very soon become burnt away in the middle, and bent so as to be totally useless; and, in some cases, they actually melt and separate in the centre

An ingenious manufacturing chemist in Dublin, some time since, constructed some furnace-bars that have properties so superior to any that we have ever seen, that we are tempted to give a perfect description of them for the benefit of our readers, more particularly as they have been used for a considerable time by Mr. George Manwaring, engineer, of Marsh-place, Lambeth, whose report upon their advantages has completely confirmed our opinion of their great value; we therefore feel no necessity for apology in laying them before our practical readers, who will, at all times, be better pleased with one practical fact proved by experience than twenty ingenious suggestions, the value of which is at best problematical.

Figure 3, shews a section of one of these improved cast-iron furnace-bars; *fig.* 4, a side-view; and *fig.* 5, a top or bird's-eye view, drawn to the same scale; and *fig.* 6, is a representation of several of them lodged upon a bearing-bar in the fire-place, as they are placed when in use.

It will be seen from the foregoing figures, that there is a semi-cylindrical hollow, or furrow made all along the middle of the top of each bar, and that each side is thinned away below very considerably to the web or fin which forms the central and supporting part of each bar in the middle of it. And it is yet doubtful whether the great durability of these bars be owing to the lodgment of ashes from the fuel in the hollow top of each bar, and which, acting as an imperfect conductor of heat, prevents the immediate action of the fire upon it, and the consequent formation of clinkers, or whether it be owing to the rush of air from below, which has the effect of cooling the bars in its passage to the fire, or, which is most likely, the joint action of both these causes; however this may be, the effect is, that these bars endure the action of the fire for a great length of time without receiving any injury, or being, in the least degree, altered in shape or form. Bars of this form are also lighter than the common ones, which is another recommendation, where large engine fire-places, or coppers, are to be erected. We would also recommend the bearing-bars to be cast with a furrow underneath, as shewn by the section in *fig.* 7; this will have the double advantage of keeping the bars cool, and also save a considerable quantity of iron.

In the construction of the flues or chimnies of furnaces, and all sorts of fire-places, it will be desirable to have the sides as smooth as possible, and for this purpose those bricks that have the best surfaces should be chosen, or, if they be rough, they should have one side made smooth by rubbing, and that side should be placed internally; by these means, the air will have less friction, and, consequently, the draught will be increased in proportion.

Another very important circumstance ought to be carefully attended to in the construction of chimnies, viz. the air, which is heated in passing through the fire, should retain its heat, if possible, till it clear the top of the chimney. Although this cannot be effectually accomplished, it may be effected as far as the non-conducting power of the materials of the chimney will admit.

Common place-bricks, as has before been stated, are non-conductors, and many fire-bricks of of loose aggregation, are still better calculated to retain the heat.

The very best method, however, of making perfect chimnies, is first to build one of very close smooth bricks, making the internal surface as above directed. This should be surrounded with a second chimney, leaving a cavity between the two about the breadth of a brick. This cavity should be filled with powdered coke, or, what is much better, powdered charcoal. The heated air would retain its original temperature much longer in such a chimney, which would also admit of its being carried up higher, and thereby obtain an increased draught.

Being satisfied that if these directions be duly attended to with a proper attention to proportions, success must be certain; but in order that nothing may be wanted to complete the object on which we have been treating, we will present our readers with a description of some furnaces, the proportions of which have been approved by persons long used to operations of that kind, and consequently capable of pronouncing a sound judgment.

On the Proportions of Air-Furnaces.

314. Although, strictly speaking, all furnaces are air-furnaces, yet, as we have already noticed, they are usually distinguished into those, where the air is forced through the fire by bellows, and those, where the air enters by means of what is called the draught of the chimney.

These are again denominated either from their construction, or the peculiar uses to which they are applied. Generally speaking, the furnaces used in chemical operations, and for melting and refining metals are of the latter kind, or air-furnace, of which we shall now proceed to describe the parts and particular uses.

A vertical section of an air-furnace, calculated to produce very intense heat, and particularly adapted for a melting-furnace of the fixed kind, and possessing all the requisite advantages, is represented in *fig.* 8, *plate* XXXVII. A, is the ash-pit of the furnace, B the grate, C the fire-place, D the cover. The cover is formed of a cast-iron frame, with cavities to contain fire-brick, which is fixed in firmly by cement. The cover slides sideways, either to the right or left hand, to open the mouth of the furnace, some of these cover-frames have an opening in the centre, into which a plug or stopper of fire-brick is closely fitted, and which may be drawn out to enable the operator to examine the state of the fire without shifting the cover. G, F, is in place of the common flue, which here forms a part of the chimney, H. The part E, F, G, might be made solid to where the dotted line, EF, is seen, without injury to the furnace, or the recess may be used for many useful purposes, such as roasting ores, or any other substances, setting crucibles upon it to anneal before they be placed in the furnace, or a cupel may be placed there for an assay, by drawing out the plug in the door to admit a sufficient supply of air. This furnace will be found much more powerful in not having a contracted flue, and at the same time making an obtuse angle with the side of the furnace. The high ash-pit will greatly assist the action of this excellent furnace; the chimney also being made double, and the cavity filled with powdered coke or charcoal, as shewn at *i*, *i*, will assist in preserving the increased temperature of the air until it reach the top of the chimney and escapes.

Figure 9, represents a vertical section of an air-furnace designed by M. Chevenix. The sides, instead of being vertical, or perpendicular to the horizontal plane, are inverted, so that the hollow or inclosed space is pyramidical, the bottom opening, for the bars of the fire-grate, is 13 inches square, and at the top it is but 8 inches; the height being 17 inches. This peculiar form possesses the following advantages, 1st, a great surface of fuel is exposed to the air by the comparatively increased size of the fire-grate, giving great facility to the entrance of the air, which rushes through the fuel with great rapidity. 2d, The inclined sides act in some degree as reverberating surfaces, and, by narrowing the dimensions of the fire-place at the upper part, detain the air until it be completely decomposed by the fuel. 3d, This shape is peculiarly favourable by permitting the fuel to fall as it decreases, by which means it keeps enveloping the

crucible without the assistance of the operator. In these kind of furnaces, the greatest heat prevails at about three inches above the grate, therefore the bottom of a crucible, or melting-pot, should never be permitted to approach nearer to the bars than the given distance. It being found both dangerous and inconvenient to stir the fire frequently when a crucible is in it, and under a high degree of temperature, this kind of furnace will completely preclude the necessity of so doing, the fuel being found, at all times, to descend freely, and thereby render the operation of stirring quite unnecessary.

a, is a grate composed of bars; *c*, *c*, are two bricks or lumps which may be let in at pleasure to diminish the internal capacity of the fire-place; *b*, is another grate, which can be placed upon the bricks *c*, *c*, for smaller purposes: *d*, *d*, are bricks or lumps, which can be placed upon the grate *b*, to diminish the upper capacity, so that, in fact, there are four different sizes in the same furnace. The bricks or lumps should all be formed, either by moulding or grinding, to the slope or inclination of the sides of the furnace, and fit in with accuracy. They are then totally independent of the pyramidical form of the furnace.

Such a structure as this is admirably adapted for an experimental chemist, as the smallest size may be obtained, and which will be found to act as well in proportion as when the largest means are used.

Another air-furnace of great power, and very convenient for many operations, has been constructed by Mr. Mushet, in his numerous and valuable experiments on iron. *Fig.* 10, is a vertical section of an assay, or melting and annealing and also a reverberatory furnace, for fusing in very high heats with pit-coal. A, is the assay-furnace, B the reverberatory-furnace, and C the annealing or cementing furnace.

The assay-furnace is cased in cast-iron, with a flanch projecting inward the breadth of a brick and about half an inch more, which serves instead of bearers for the fire-bars, see *a*, *a*, *figures* 10 and 11. Upon this flanch the brick-work is reared, which should be of good fire-bricks on the bed. The furnace is nine inches square, and the total height is 27 inches, from the top of the flanch to the bottom of the flue. The interval is 18 inches, the flue is four inches high, the height above is five inches; flue seven inches long, and keeps opening into the chimney, as may be seen at *b*, *fig.* 12. If the chimney be under 25 feet in height, a larger flue is requisite; and if beyond 35 feet, a smaller flue will throw the heat more regularly through the furnace. It should, however, be observed, that more harm ensues in a flue too small than in one too large, a small flue having the effect of wire-drawing the current of air in such a manner as to check the draught very considerably. *c*, *c*, is the ground or floor line, which also represents the edge of a grate that covers the ash-pit, which will be better seen in the plan, *fig.* 12, at *d*. This grate is nine inches from the fire-bars, and covers a small vault beneath, giving ample room for air to enter and advance to the fire, and forming a bearing for the operator to stand upon.

e, *e*, in *figures* 10 and 11, is the ash-pit. In *fig.* 12, which is a ground-plan of the chimney

and furnaces, C, is the annealing or cementing furnace in which crucibles are baked to a bright red heat, before they be introduced along with the matter to be operated upon into the assay-furnace. It also serves instead of a cementing-furnace, being easily made to produce a heat of 100° of Wedgewood. It may also be made of any size, from 9 to 14 inches square, a nine-inch chimney being sufficiently wide to the extent of an 18-inch furnace.

The chimney to each furnace is carried up five feet perpendicularly, they then gradually incline to the centre openings, which they enter about 12 feet above the flues; *d, d, d,* are dampers: from the grates of this assay-furnace to the top of the chimney is 33 feet.

This furnace has melted 400 grains of maleable iron in ten minutes, and half a pound from lumps in forty minutes. If the materials to be operated upon be prepared with judgment, any experiment to the extent of half a pound of matter may be performed in half an hour, and less quantities in much less time. When approaching to its highest degree of temperature, a Stourbridge clay crucible (which usually drops at about 168° of Wedgewood) will disappear in fifteen minutes from the time of its being put in. The first five minutes brings it to 140° of Wedgewood, at which cast-iron boils. Steel boils in it at 162°, and maleable iron boils at 170° to 172° of Wedgewood. It is, however, probable, that the advantages of this furnace do not result from the height of the chimney, (which is certainly not great,) nor from the size of its openings; it is more likely that it depends upon the flue, the opening of the grate-bars, the size of the fuel, and the care that is taken in feeding it.

On the Nature and Properties of Reverberating Furnaces.

315. In many of the processes of metallurgy, it is found necessary to divest the dross of metal of certain substances, which become volatile under a considerable degree of heat, continued for a greater or less period of time, according to circumstances. This process is technically called *roasting,* and it is most frequently done in a reverberatory furnace. This kind of furnace differs from the air-furnaces, previously described, in the following particular; namely, that, instead of the heated air being allowed to escape freely up the chimney, it is made to strike or impinge on the ore as it lays upon a hearth, and when the impure materials contained in the metal are rendered volatile by the heat, they are carried by the rarified current up the chimney and dissipated in the atmosphere. One of these furnaces is represented in *plate* XXXVIII, *figures* 1 and 2. *a, fig.* 1, is the ash-pit, and *b,* the fire-grate; *c,* is a bridge over which the flame and heated current passes, and is directed upon the hearth *d,* by the dome or arched covering, *e. f,* is the chimney, and *g,* is a door closing the opening where the metal is introduced, and also withdrawn when necessary. All the parts near the fire should be constructed of the best materials for resisting the effects of heat, particularly the bridge, as the upper part will be exposed to the greatest effort of the flame, for in this kind of furnace pit-coal is most generally used.

When some kinds of metal are placed in furnaces of this description, it is with a view to convert them into the state of an oxyde, for which purpose it is necessary a current of pure air should pass over the surface, in order that the oxygen of the atmosphere may combine with the metal as rapidly as possible. But when the air has passed through the fuel in the fire-place, and parted with its oxygen, it is not in a fit state for the purpose before stated. This difficulty is completely overcome by constructing an apertnre in the bridge, as shewn at *h*, which has a communication with the atmosphere at one end, the other part within the furnace, is open through the bridge the whole of its length, by which means a sheet of pure air is introduced over the surface of the metal, and by these means oxydation is effected very rapidly.

The red oxyde of lead, commonly called *red lead*, and also *putty*, the white oxyde of tin, is rapidly formed in furnaces of this kind. The plan, *fig.* 2, has the same letters on the corresponding parts.

On the Method of Constructing a Watch-Dial Plate and Enamellers' Furnace.

316. The great simplicity and usefulness of the dial-plate maker's furnace will render it a valuable appendage to the laboratory, and also to all persons who may have any taste for the beautiful art of enamelling. It will likewise be exceedingly useful for many experiments, where it may be necessary to watch the progress during the time that any substances may be submitted to the action of the fire.

This furnace is singularly adapted for the purpose to which it is applied, for an intense heat may be obtained in a very short space of time, and with a comparatively small quantity of fuel, in addition to which, objects placed in it may be brought almost in contact with the coals, or rather coke, without receiving the smallest injury from their dirt or ashes.

Plate XXXVIII, *fig.* 3, represents a front elevation. *a*, *a*, are two piers upon which the arch *b* is carried; over this is placed the iron plate, *c*, forming the bottom of the furnace; *d*, *d*, are the sides formed by large square Welsh lumps, the back being the same; *e*, is an iron bar, or lintel, which supports the front of the chimney; *f*, is a register or damper, and *g*, is a simple arch of clay, called a muffle, having no bottom nor ends, but being completely open. In front, the muffle rests upon a piece of iron, shewn at *fig.* 5, the back end being placed upon the coke, which is the fuel used in this case. In the vertical section, shewn at *fig.* 4, an iron plate or hearth is shewn at *h*, upon which the iron door, seen at *i*, rests, when it is placed in front of the fire-place. This iron door has an opening or aperture made through it, exactly corresponding, in shape and size, with the end of the muffle, and through which the fuel is supplied with air. The fuel is built around the muffle, as shewn in the elevation, a large and solid piece of coke being placed at the back end of the muffle, to prevent the smaller cokes from entering the space under the muffle. The coke is ignited by placing lighted charcoal under the muffle, which, in a little time, will burn partly away, and, being pressed or beaten

down, will form a clear bed on which to place the work. This very simple furnace is known only amongst the enamellers of watch dial-plates, with whom it is found extremely convenient, and for many other purposes it would be found exceedingly convenient, were it more generally known. There is one great advantage attending this peculiar construction, which is, that a very moderate height of chimney will be sufficient, for in most cases, these furnaces are built in the attic story of the houses where they are used; the majority of persons employed in the art being in the habit of carrying on their business at the top of their houses. We have known an addition made to this furnace that was sometimes very useful, which was as follows:—The iron plate forming the bottom was placed so that it could be taken out, and under it was placed a set of bars, the part under the bars being open, so as to permit a supply of air in that direction, the door was placed before it as usual, and the aperture being stopped, the whole acted as a wind or air-furnace to melt any substance that might be required; in this case, iron bars or lintels were adopted instead of the arch, by which means a greater depth was obtained to hold the fuel when it was used as an air-furnace.

Having given an account of the principles, and described some of the varieties of air or draught furnaces, we shall now describe one of those furnaces which are supplied with air by mechanical means, and which are called blast-furnaces.

On the Properties and Construction of Blast-Furnaces.

317. The term blast is used at iron-foundries to denote the column of air forced into the furnace for the combustion of the fuel, and consequent reduction of the metal from the ore. Its velocity is occasioned solely by the power of the blowing machine forcing the whole contents of the air-pump through apertures which enter near the bottom of the furnace, called nose-pipes; and, according to the absolute power of the engine, air of various degrees of density may be produced; whereas, in *air* or *wind* furnaces, a power equal to the density of the atmosphere is all, at the most, that can be produced.

Combustion, in the blast-furnace, consists chiefly in the rapid reduction of a given quantity of solid fuel, and its accompanying portion of ore, in the shortest possible time. That furnace and that blast which can, in a given time, reduce the greatest quantity of fuel, all things else being alike, will always manufacture the greatest quantity of iron. Some idea may be formed of the enormous quantity of atmospheric air which is necessary to supply a blast-furnace, when we state, that to manufacture thirty tons of iron per week, it will be necessary to blow into the furnace 3000 cubic feet of air per minute. This circumstance will show, in a very striking degree, the difference between the air and blast furnace.

Some blast-furnaces are constructed externally of a quadrangular form, and sand-stone is the material most commonly used for the outside or body of the building; they are sometimes conical, and formed of good bricks on the outside, the insides of all being lined with the most

refractory materials that can be obtained. In almost every case, and in whatever way they may be constructed, the most prominent cause of their destruction is the great expansion of the materials that takes place from the immense heats that are generated in them. Iron binders of various kinds have been adopted, and the most approved mode of uniting the several parts have been practised; but in almost every case, such has been the effect of heat, that rents and cracks have been made, defying the ingenuity of the most experienced workmen to remedy or prevent. In some instances, excavations have been made in the solid rock, with the hope that the solidity of the materials would resist the effects of heat, but in vain; for when the temperature of the furnace was raised to its necessary height, the solid rocks were rent asunder in the same manner as the labours of the most ingenious workman. Some iron-masters, seeing how hopeless it was to make a solid and lasting structure, formed an external shell, and also an internal one likewise, leaving a space between the two, which was loosely filled with sand-stone of various sizes, hoping that, when the internal shell or lining expanded, the stones between the two would yield by becoming wedged, and by these means, although the inner shell or lining was split, yet the external one would remain entire; in some cases, the outside part was preserved, but when the internal part gave way, it opened a passage for a current of air through the loosely arranged and broken stone, which was found very injurious to the process of smelting, and ultimately that plan was relinquished.

There is one circumstance that we fear is productive of much mischief, and which ought to be guarded against with all possible care: we mean the great quantity of water that sand-stone holds in its pores, more especially if it be used immediately that it be brought from the quarry. We may also add the quantity of water used with the mortar, which, with that in the stone, will constitute a weight of many tons. To evaporate this by very gentle means would be a work of much time, far more we are inclined to believe than is ever bestowed upon it; therefore, when the blast is applied, and the heat raised, the expansion, both by heat and also the effect of steam, generated from the imbibed water, is such, that no structure we are acquainted with can ever withstand it. The only mode then seems to be, that of repairing the breaches, from time to time, in the best manner possible.

In order to assist the evaporation as much as possible by artificial means, cylindrical cavities round the body of the building should be formed, having outlets at as many places as may be convenient, say not more than four or five inches apart, by which means the water may be made to escape from the more solid part of the structure, in a manner that would reduce in a considerable degree the time that must otherwise be employed for the same purpose; and as all furnaces are more or less subject to similar circumstances, the same precautions should be observed, in order to ensure success.

As there are various opinions concerning the exact form of a blast-furnace, many of which are merely hypothetical, we shall give a vertical section of one that has been long adopted,

leaving the practical workman at liberty to adopt such other shapes, proportions, and forms, as may be desired by his employer.

Fig. 5, plate XXXVIII, represents a vertical section of a common blast-furnace. *a, a,* shews the position of the hearth, which is two feet square; *b,* the top of the hearth, two feet six inches square; *a, b,* the height of the hearth, six feet six inches; *c,* the lower part, and *d,* the upper part of a frustum of a hollow cone, technically called the boshes, and which it will be seen unite with, and terminate of the same size as the top of the hearth, the boshes being circular, while the hearth remains square. The top of the boshes, in diameter, is 12 feet, and 8 feet perpendicular height; *e,* is the top of the furnace, where the materials are put in at, which, technically speaking, is called charging. This part is three feet diameter; *e, d,* represent the internal cavity of the furnace, being the frustum of a hollow cone, 30 feet high. The total height, from *a* to *e,* will be about 44 feet, which is called the working part of the furnace. *f, f,* shew the lining, formed of the very best fire-bricks, about 12 inches long and three inches thick, the ends being tapered to suit the conical form; *g, g,* shew a space or cavity surrounding the lining, which is usually filled with a non-conducting substance, namely, coke or charcoal-dust, or in some works sand is preferred, as being more likely to fall close together, and in a degree close up any split or rent, and also yielding readily to the great expansion of the lining; *h, h,* is a second lining, which is intended to prevent any part of the flame that may find its way through the internal lining from entering the external stone or brick-work, which is not calculated to bear the action of intense heat; *i, i,* are cast-iron lintels, which support the bottom of the tuyere arches: these arches are about 14 feet high on the outside, and 18 feet wide; *k,* represents the tapering nose pipe which enters the tuyere, and through which the air is conveyed from the blowing cylinder.

Fig. 6, represents the foundation of the hearth, and a view of the method of constructing the false bottom; *l, l,* the bottom stones of the hearth; *m,* a stratum of bedding sand; *n, n,* are passages of escape for the damps that arise; *o, o,* are piers of brick. The plan of the parts placed below have similar letters on the corresponding parts.

Fig. 7 shews a vertical section, at right-angles to the one shewn in *fig.* 5 of the part called the boshes, in which the position and form of the tymp and dam-stone will be plainly seen: *a,* is the tymp-stone; *b,* the tymp-plate, which is firmly fixed to the side-walls of the hearth; *c,* the dam-stone, which extends the whole breadth of the hearth, except about six inches, which is filled, when the furnace is at work, with a strong sort of binding sand. This stone is surmounted by an iron plate, called the dam-plate, shewn at *d.*

The space under the tymp-plate, for five or six inches down, is rammed every cast full of strong loamy earth, and sometimes even with fire-clay. This is technically called the tymp-stopping.

On the Construction of Fire-Places for warming Rooms in Dwelling-Houses.

318. Having concluded our observations on the methods of constructing a variety of furnaces, and fire-places for heating vessels, and performing various other important operations, we shall close this department of the work with some observations on the principles that should be observed in fixing stoves for the purpose of warming rooms or apartments in houses.

It should be remembered, that, in the foregoing subjects, each and every one of them are either used to communicate the heat generated to vessels containing some liquid or material to be heated, or else they are used to liquify metallic or other substances placed in actual contact with the ignited fuel, the whole of which is completely inclosed within walls composed of earthy materials. But, in the class of fire-places now to be considered, the ignited fuel is always open, and fully exposed to view, the effect of heating being produced entirely by radiation.

There are few departments of the art that call for more skill, than that of setting fire-places for our ordinary apartments, for if they be not executed in a proper manner, every comfort in a room may be destroyed.

In order to produce the greatest degree of heat in an apartment, many persons are desirous of having their stoves set as forward as possible, in which case there is certainly something gained in point of heat, but it is generally at the expence of having every thing in the room covered with the ashes that fall from the fuel, and hence that accumulation of dust on the furniture, in some apartments, which is almost unbearable. In other cases, where it has been attempted to avoid this evil, stoves have been placed so far back in the fire-place, that the greatest portion of the radiant heat is carried up the chimney, acting in no other way than to create and increase draught, without augmenting the temperature in proportion to the consumption of fuel.

Count Rumford, who investigated the nature and properties of fire-places, and the economical use of fuel in general, observes, that our fire-places are mostly too large, or rather it is the throat of the chimney, or the lower part of its open canal near the mantle, and immediately over the fire, that is too capacious. We must, however, admit, that while chimnies are swept, as at present, by the barbarous practice of climbing-boys, a great part of this inconvenience in the construction must remain; this may, however, still be remedied by proper appendages to stoves, which will be presently explained; but, as the immoderate size of the throats of chimnies is the great fault of their construction, it is this fault which ought always to be attended to in every attempt that is made to improve them.

As the smoke and vapour which ascend from burning fuel, rise in consequence of their being rarified by heat, and made lighter than the air of the surrounding atmosphere, it is clear the nearer the throat of a chimney is to the fire, the stronger or more rapid will be its draught, and, consequently, the less danger will there be of its smoking; the only thing to be apprehended is, that the fuel will be too rapidly consumed.

It is very clear that the greatest part of the heat of fuel consumed in open fire-places, is projected into the space to be warmed by radiation; but, by proper contrivances, much may also be obtained by reflection, from suitable materials placed in the most beneficial position for that purpose.

The best form for the vertical sides of the chamber of a fire-place, or what are usually called the covings, is that of an upright plane, making an angle with the plane of the back of the fire-place, of about 130 degrees, which will reflect the heat in such a direction from each plane, that various intersections will take place, and, consequently, a general dispersion of the rays will ensue. But, where the covings are placed so as to stand at right-angles with the plane of the back, the reflected rays will never enter the space of the apartment, the whole of their beneficial influence being entirely lost.

It is a well-established fact, that all bodies that absorb radiant heat, are necessarily heated in consequence of that absorption. It is therefore very desirable that we should be well acquainted with the nature and properties of the materials used, in order to prevent a failure from an improper choice of them. The method of ascertaining the absorbent and reflecting properties of materials is very easy, namely, by exposing them to the direct rays of a clear fire, when those that are last heated in a given time will evidently have absorbed the least caloric, and are therefore to be chosen as the best reflectors. Fire-stone, fire-bricks, and most of the earthy cements, are slow conductors of heat, and consequently good reflectors, the worst material being metal of any description; but from its neat appearance and durability, when combined with its cheapness, it is most likely to exclude from general use those materials whose properties are for this purpose so much more valuable.

When bricks or any earthy material is used for forming the covings or sides of fire-places, they should be covered with a coat of plaster, or what would be much better, Dutch tiles. The whole interior of the throat, or covings, should be kept white, instead of the dingy black and sombre tint now universally adopted; for it is a well known fact, that white, as a colour, reflects heat, while black, on the contrary, absorbs and retains it.

Where the throat, or lower chamber of a fire-place, is of necessity obliged to be of dimensions inconveniently capacious, the best stove for such a fire-place is that known by the name of *register stove;* for by the peculiar construction of this kind of stove, the throat will, in effect, be narrowed, while sufficient room will be obtained for the passage of a climbing-boy. We have no doubt that many chimnies where register-stoves are used are liable to a return of smoke in some instances, but as the open space behind the register forms a chamber to receive it, it rarely or never enters the room, and therefore is no evil. A simple method of producing the same effect, and at a very small expense, was some years since invented by Mr. Edmund Turrell, Engraver, and as it proved very successful, we shall give a brief description, for the benefit of our practical readers, more particularly, as it is calculated to benefit many of those who follow sedentary pursuits.

There are, perhaps, no evils attendant upon sedentary pursuits greater than those which arise from the want of attention to proper ventilation of the apartments where persons so engaged follow their daily avocations. It is no uncommon circumstance, on entering the attic workshop of a watch-maker, to find him enveloped in a highly-rarified atmosphere, the temperature of which will seldom be less than from 75° to 80°. This is, in most cases, produced by a German stove, which is supplied with air from the lower part of the apartment, and which is indeed the only part that receives any fresh supply. But the upper part of the room is continually heated, and there being no means of escape for the air so heated, the unhappy victim is under the necessity of breathing the same atmosphere over and over again repeatedly, until, at last, there is scarcely any oxygen remaining in it to supply the blood with, and for want of this, the liver becomes enlarged or diseased, and the inhabitant of such a place assumes the appearance of those persons who live in hot climates.

There is no doubt that a large proportion of these evils arise from inattention and ignorance, but much is endured from real necessity, for in almost all cases, persons of this class feel it absolutely necessary to occupy the attic rooms, on account of the superior light they obtain there, and as the chimnies of such rooms are always short, the natural consequence is that they smoke insufferably if an open fire-place is used. This inconvenience has occasioned the necessity of using German stoves, the pipes of which being carried some distance up the chimney, has the effect of preventing the smoke from returning into the room.

Upon investigating the cause of this circumstance, it was found that when the iron-pipe was carried some considerable distance up the chimney, or was made to enter it near the ceiling, there was a space formed around the pipe in one case, and beneath it, in the other, to receive the smoke when it made a momentary return, and this it was which prevented the entrance of it into the room; and, in addition to this circumstance, the iron pipe being a good conductor of heat, the air in the chimney was kept so much rarified, that the return of the smoke was rendered much more difficult. Seeing, from long experience, the great advantages of this method of preventing smoke returning, it was conceived that the same advantages might be obtained by applying it to an open fire-place, which proved highly beneficial, when arranged in the following manner:—

319. *Plate* XXXIX, *fig.* 1, represents an open fire-place, with a common pantheon-stove fixed in the usual manner. A, represents the section of an iron pipe which terminates at the bottom in the funnel-shaped portion, B, which is made to fit the covings very closely. C, C, represents the space or chamber that is formed to receive the returning smoke; and in order to show the whole to greater advantage, the chimney is shown in section as low as the breast D, D, the funnel is fixed to the covings by pins of iron, or screws, which can easily be withdrawn when it is requisite to remove it, and the pipe should be made in short lengths, the joints being fitted very loosely, a provision that will render it easy to be removed when the chimney wants sweeping. This invention contains in part the advantage of the narrowed throat, without the disadvantage

of excessive draught. It may also be made to answer as a register, if a damper, moving on a centre, be fixed at the bottom of the pipe near B; but its greatest advantages arise from its property of rarifying the air in the chimney, and the formation of a chamber to receive the smoke at any time that it makes a return in the chimney.

Almost any chimney may be cured of smoking, if the mantle is sufficiently lowered so as to limit the opening for the passage of the atmosphere; but in that case it is well known that the fire-place is converted into a species of air-furnace, in which state it will communicate scarcely any heat by radiation, while the consumption of fuel will be enormous in proportion to the effect produced. The skill of the practical workman is, in such cases, much required.

In many instances, chimnies continue to smoke as long as the door of a room is closed, proving thereby that a constant supply of air is requisite. In such cases, a complete cure may be effected by conveying air from without by means of a pipe, which should be made to enter beneath the grate, and by this means the unpleasant necessity of remaining in an apartment with the door always open will be avoided, and the fuel abundantly supplied with fresh air to carry on the combustion.

We are well aware that many local circumstances will frequently tend to make the cure of smokey chimneys a desideratum; but the practical bricklayer will do well to make himself acquainted with the general principles herein given, by the careful application of which he may hope to overcome many of the difficulties hitherto considered unattainable.

CHAPTER X.

320.—AN EXPLANATION OF THE TERMS, AND DESCRIPTION OF TOOLS, USED IN BRICKLAYING.

Many of the technical Terms applicable to this Art are also used in Masonry, therefore those that have been described in the Terms of Masonry, page 83, will be omitted here to avoid useless repetition.

Alumina, is the plastic principle of all clays. It is one of the primitive earths, and when pure is perfectly white; all colour in clays being produced by some metallic oxyde, or some other substances mixed with them.

Bed.—The under-surface of bricks when laid in any kind of work.

Bedding.—The art of laying bricks in such a manner, that they may bear their weight equally on every part of their beds or under-surface. Work is well-bedded when no rocking motion can be produced, by bearing partially upon the upper-surface at either end. The

plastic and pliant state of mortar makes this operation an easy task, therefore it is frequently laid even upon the earth in sufficient quantities to bed bricks in, as in the case of paving.

Bedding-Stone.—A plane surface of marble used to try the beds or rubbed sides of bricks, and thereby detect any winding in the surface.

Bond or Bonding.—A technical term used both in bricklaying and masonry: it means such an arrangement, or combination of bricks when laid upon each other, that the perpendicular joint formed by any two adjacent bricks may, at all times, be covered by the centre (or nearly so) of one laid immediately over the joint, by which means the nearest approximation to solidity will be attained that such materials are capable of producing. For a further description of this essential quality, see page 96.

Bond Timber.—Square pieces of timber laid in walls, on the inside of buildings, at intervals above each other, to prevent the separation of brick-work in a perpendicular direction.

Brick Axe.—An instrument used to cut off portins of bricks before they are rubbed upon the rubbing-stone; by a dexterous use of this tool large portions of those bricks intended for arches may be cut away, so as to save a great deal of time in rubbing.

Brick Trowel.—This is the principal tool of the bricklayer; it is used to lay and spread the mortar, also to cut even the hardest bricks. When really good, they ought to do this without gapping or notching; they used to be made of iron, edged with steel, but the trade are indebted to Mr. George Walby, for the invention of making trowels entirely of steel. The valuable properties of his trowels may perhaps be equalled, but will, we think, never be exceeded.

Bricks, are a species of artificial stone; for an accurate description of the various kinds, see page 88; and of Roman bricks, see page 90.

Burrs.—Bricks that are completely vitrified, and on that account frequently adhere together in large masses, when they can be separated, they are the best to place in foundations.

Buttress.—A projecting mass of brick-work attached and combined to walls to assist in supporting them, see *plate* XXIX.

Cambered.—Any kind of work that partakes of the properties of an arch.

Camber Slip, is a piece of board, of any length or breadth, made convex on one or both edges, and generally something less than an inch in thickness; it is made use of as a rule. When only one side or edge is cambered, it rises about one inch in six feet, and is employed in drawing the soffit-lines of straight arches; when the other edge is curved, it rises only about half that quantity, and is used for drawing the upper side of the arch, so as to prevent its becoming hollow by the settling of the arch. But some persons prefer having the upper side of the arches straight, in which case the upper edge of the arch is not cambered. The camber slip should be sufficiently long to meet any case that may present itself.

Clamp.—A term used to denote a large mass of bricks, laid in a certain order, to be burned in the open air. The new or unburned bricks are usually protected by an external covering of bricks already burned.

Clay.—The earth always used to make bricks with. When pure and unadulterated, it is white after being burned, as is the case with pipe-clay, which is nearly pure, but not quite, there being a considerable portion of silex combined with it, which is also white when burned, without being vitrified; for a description of this valuable material, see page 88.

Clay Mill.—This is used to separate stones and coarse gravel from impure clays; for a description, see page 90.

Coal-Ashes.—These are used, when sifted very fine, to mix with lime; those produced by smiths in their forges, they being partially vitrified, are the best. The composition, called coal-ash mortar, is used to point or fill up the interstices or joints of brick-work, and to receive upon its surface the white lines of tuck-pointing.

Float-Stone.—This is used for taking out the marks of the axe, and smoothing the surfaces of curved-work, such for instance, as the cylindrical backs and spherical heads of niches. But, for this purpose, the *float-stone* must itself be curved in the reverse form, though of a radius equal to that intended for the brick, so that it may coincide with it.

Foundation.—The surface upon which the first layer of bricks of any wall or building are laid; see page 100.

Groining.—Groined arches are those whose lines of continuation meet each other at any angle and form a junction, producing thereby various intersections; see page 111.

Grout.—Mortar, or any other cement, reduced to a liquid state with water. It is usually poured over each layer or course of bricks, by which means the work is made solid, the liquid grout completely filling up the interstices.

Hammer.—One end of this tool is formed like the common hammer, and the other is shaped like an axe, the cutting edge of which is not more than an inch and a half long. By the projecting length at the cutting end, it is well adapted for making holes in walls, by being used as a chopper.

Headers, are those bricks that show only their ends on the outside or inside of a wall or building, their whole length being laid perpendicular to the face of the wall, and crossing those called stretchers, at right angles.

Inverts, are those arches usually resting on the foundation of earth being turned upside down, in which position they are well adapted to resist pressure, the piers of buildings being usually made to rest upon the springings. For an example of the application of such arches, see the Plate of the Wall of Coldbath-Fields Prison, page 103.

Jointer.—A steel tool, nearly in the form of the letter S; it is used to mark lines or indentations in the joints of brick-work, where tuck-pointing is omitted.

Lines and Pins.—The line, when strained over each course of the quoins by the pins, enables the workman to keep all the rows or courses of work parallel.

Marls.—Bricks made of clay, nearly pure, their colour being a fine yellowish gray; the best coloured ones are called *firsts*, and those not equal in point of colour are called *seconds*;

see page 90 : the softest of the *firsts* are used in the construction of arches, as they are easily cut and rubbed into any given shape or form, which is performed, first, by cutting with an edged tool called an axe, and then rubbing them upon a sharp grit-stone with dry sand.

Mould.—This is used for forming the face and back of the brick to its proper taper; and for this purpose one edge of the mould is brought close to the bed of the brick previously squared. The mould has a notch for every course of the arch.

Niche, is a recess in a wall, the principal object of which is to relieve a large plain surface, and also to hold a figure or any other ornamental device. They are semi-circular, semi-eliptical, having a hemispherical canopy or head. They are sometimes made simply hemispherical.—See page 120.

Oven.—An arched cavity, having a floor made of tiles, the roof or arch is made of the same materials. It is used for baking food and other purposes.—For a description, see page 131.

Pargeting.—A mixture of good mortar and a certain portion of cow-dung, it is used to plaister the internal surfaces of chimnies with, making the surfaces smooth, and filling up any interstices in the brick-work. It also contributes to prevent accidents by fire.

Paving-Bricks.—Red stock-bricks, well burned, are the best kind for this purpose; where very good work is required, they must be chosen quite free from curvature, which sometimes happens in burning them.

Place-Bricks.—These are made of the same materials as stocks, but they are always soft, being very slightly burned; they may, on that account, be more easily cut; and being non-conductors of heat, are fit for many purposes where that quality is indispensable.

Pointing Tools.—Small trowels used to lay on the pure lime used in tuck-pointing.

Quoins.—All those bricks that are used to form the corners or solid angles of any wall or building.

Red Rubbers.—These are bricks made of the natural clay without any mixture, they are therefore red when burned, and very equal in their texture.—See page 90.

Rubbing Stone, is a rough-grained grit-stone about twenty inches diameter; it is usually laid in a bed of mortar on one end of a strong bench, called a *banker;* upon this stone the bricks that have been cut with the axe are to be rubbed until they are brought to the proper shape, and sufficiently smooth on their surfaces.

Saw.—This is made of a piece of flat tin. It is used to cut lines about the eighth of an inch deep in those bricks that are to be cut by the axe. By this method rough jagged edges will be prevented, which would be the case if the axe was used without such a manipulation.

Sewer.—An excavation under ground used as a water-course, the bottom and sides are formed of brick-work, the top is formed by an insisting arch, the bottom being an inverted arch. —See page 129.

Shaft.—A hollow tower of brick-work, which is sunk like a well under ground; it is used as a passage to descend to mines or tunnels, placed at a great depth below the surface of the earth.—See page 126.

Skewback, is the sloping plane upon which the springings of a straight or scheme arch rest on each extreme.

Skewing.—A technical term for sloping or inclining.

Sleepers, are thick planks of timber, laid down on a foundation of earth, upon which brick foundations are laid, in order to prevent partial sinkings or settlements in the walls of buildings.

Springings, are the bricks on each side of an arch that rest upon the piers or abutments, the plane of their bases being parallel to the horizon.

Stocks.—These are bricks formed mostly of impure clay and coal-ashes, the gray colour on their surfaces being produced by Thames sand, which is imbedded in them, while the clay is wet and adhesive. These are considered next in quality to marl seconds.

Stretchers, are bricks laid in the direction of the length of a wall; they form bond by laying across the joints of *headers*.

Throat.—The contracted part of any open fire-place, through which the rarefied air passes with an increased velocity proportionate to its internal area. The nearer it is to the fire, the greater, generally speaking, will be the draught.

Tunnel.—An excavated line under ground, each end opening upon the surface of the earth. It is used to form a passage through hills, parts of mountains and rocks; also to form a roadway under a river where a bridge would be impracticable.—See page 121.

Vaulting.—A method of covering excavated spaces under ground, which are used to keep various stores in. When the arched roofs of vaults run in various directions, and intersect each other, they are called Groined Vaulting or Arches.—See page 108.

BOOK III.

PLASTERING,

PLAIN AND ORNAMENTAL.

INTRODUCTION.

321. THE exact period when the art of Plain Plastering was invented, cannot, owing to the want of sufficient data, be positively determined; but it must readily occur to the mind of every thinking man, that necessity must have been the inventor, and time its great improver.

On referring to the huts of the primitive inhabitants of the universe, more particularly those of the northern parts of Europe, we find that the interstices, which occurred between the timbers or wicker-work, were filled up by means of clay or mud, in order to protect the inmates from the severity of the weather, and which is indeed practised at the present day by the peasantry of this country.

In process of time, when civilization had rendered man more susceptible of elegance and convenience, the surfaces of the walls were made smooth and straight, being, in some instances, painted, in a style much practised by the Romans, and known to the moderns by the name of fresco, as many examples discovered in the excavations of Pompeii and Herculaneum will prove.

That the Romans, at a very early period, practised the art of plain plastering, is sufficiently evident by the portions which remain attached to the walls of some of their most ancient buildings, the antiquity of which must be considered as proved, when we look at the manner in which the carbonic acid contained in the atmosphere has acted upon the lime and sand, it having reduced the various particles into a solid and compact substance resembling stone, and which, indeed, is a carbonate of lime, defying the most dexterous applications of the hammer and chisel to separate it from the walls without bringing off pieces of the stone attached to it.

Connected with this art, and indeed belonging to it, is one of the most elegant branches of decoration, formerly called stucco-working, but now known by the more comprehensive title of Ornamental Plastering, including modelling, casting, and working in stucco.

The invention of stucco-working has been attributed to Margaritoni, an Italian, who died in 1317.

The materials used by him were sifted lime and white marble pounded, which were kneaded together to the consistency of potter's clay, pure water alone being used in their amalgamation.

The method practised by Margaritoni, in the working of stucco, was the laying a body of the material on a ground prepared to receive it, which, while in a plastic state, was made to assume the form required. The tools used for this purpose were of a very simple construction, being merely a piece of steel, about 12 inches long, formed at one end like a small trowel, and the other end round, which is now technically called a *boasting* tool, from its being used in giving the first shape to the work; several smaller ones, of similar construction, were used for the finishing.

Vittoria (a pupil of Giocomo Tatti, a celebrated sculptor of Venice, contemporary with Michael Angelo) has the credit of perfecting the working in stucco. He unquestionably introduced a different method of working, which difference consisted in pressing the plastic stucco into moulds of wood, lead, or baked clay, previously dusted with finely-sifted lime. By this means, the face-work and outline were produced; the part so formed was separated from the mass, bent by the fingers to the necessary shape, and afterwards attached to the ground by a little soft stucco, which served as a cement for the connection of the different parts of the ornament.

This manner of working has been called patted and pressed work, but how far it was a perfecting of the original mode is problematical, when we recollect that the execution must of necessity have been limited to the production of such designs as it was possible to make moulds for; whereas, in the former method, the general effect, as well as the most simple details, depended entirely on the judgment and ability of the artist, who required an intimate knowledge of nature in her animal and vegetable kingdoms.

The manner of patted and pressed work has been entirely superseded by the improvements which have been made by the moderns on the method, the first principles of which were invented by Margaritoni, together with the casting of plaster ornaments in wax-moulds, which was invented by one of our own countrymen.

In the year 1703, during the time that Rose was employed in the ornamental work at old Buckingham-house, a dispute arose between him and his Italian stucco-workers, respecting the remuneration for their labour. He being unwilling to accede to their (what he considered) unreasonable demands, set his ingenuity to work, and was successful in inventing the casting of ornaments, by pouring plaster of Paris, in a liquid state, into moulds composed of a mixture of rosin and bees'-wax, so that the major part of the embellishments, which had hitherto been executed in stucco, were cast, and fixed in their proper situations with plaster mixed with water until it had attained the consistency of paste.

322. Before entering into a further description of the different methods of working in stucco, it will be necessary to trace the origin of ornament and its introduction into architectural decoration. For this purpose, we must revert to Egypt, the cradle of the arts and sciences. The great progress which the Egyptians had, at a very early period of history, made towards civilization, naturally attracts the attention to their country as the place where ornament had its origin.

At the annual overflowings of the Nile, the hollows of the earth which remained filled with water (after the retiring of the main body) were seen covered with numerous aquatic plants, the most beautiful of which was the lotus or water-lily. This plant, no doubt, at once presented itself to the unsophisticated minds of the Egyptians as the most appropriate emblem of the annual inundations upon which the fertility of their country so much depended, and hence its introduction into architecture.

Thus we find the earliest examples of the Egyptian column made to represent a bundle of lotus plants bandaged together, the flowers forming the capital, the stems the shaft, and the roots the base.

Owing to the proximity of Greece and Egypt, and the commercial intercourse which existed between the two countries, the Grecians were led to copy, and afterwards to improve, upon the Egyptian style of decoration, by combining the honeysuckle, and other productions of nature, with the water-lily, as may be observed in the most ancient of the Grecian temples.

We are informed by history that all the ideas of the Romans, in the art of decoration, were taken from the models of the Grecians, which will be found sufficiently evident by comparing the two styles.

The principal fault in the Grecian foliage was the uniformity of its *raffleing*, the flatness of its emboss or projection from the ground-work, and a want of energy and freedom in its face-work. The form of the Grecian raffle was pointed, and in no case was there a second raffle introduced between the burstings of the leaves, as invariably occurs in nature. These deficiencies, by a more correct imitation of nature, were considerably improved by the Romans.

In the fifth century, architecture, and, in fact, all the arts and sciences gradually began to decline in Europe, which decline was facilitated by the blind policy of the northern hordes, who, at this period, subverted the Roman empire, overran one half of Europe, and almost totally annihilated those glorious buildings which had been the work of ages, and intended to perpetuate the memory of a race of men, to whom mankind are indebted for the ground-work of most of the ideas they now possess.

We should stop here, and rest contented with what we have already said upon ornament, were it not that we prefer giving the reader a practical description of the different styles to referring him to a voluminous list of books on Architecture, many of which may be in a language not understood by the practical man, and all of an expensive description. We, therefore, now proceed to explain the different styles of ornament, in the order in which they were introduced into England, shewing the degree of connection subsisting between them up to the present time, and specifying some of the most celebrated workers in each particular style.

CHAPTER I.

Of the Gothic Style of Ornament.

323. For the space of four or five centuries after the fall of the Roman empire, a dark age seemed to reign throughout Europe; but the dawn of refinement at length made its appearance, and materially affected the building art, by the invention of Gothic architecture.

In this style nature seems to have afforded an inexhaustible source from which to draw, as we frequently observe the leaves of the oak, the maple, the thistle, and the cabbage, introduced in the capitals and running ornaments, and also the human figure, with representations of monkeys, owls, squirrels, mice, &c. &c. But embellishments in Gothic, more particularly belong to what is termed the florid style, as enrichments rarely occur in the early Norman examples to be seen at Durham, Dunfermline, and Lindisferne, except the partial introduction of barbarous looking heads, and the zigzag moulding, which cannot strictly be called an ornament, as it is, in many cases, formed by the intersections of mouldings. Its greatest characteristics are grandeur of design, astonishing effect, on account of the magnitude of its proportions, an expressive depth of shadow, and the boldness of the profiles of its mouldings. There are some beautiful specimens of this style on the Continent, in the cathedrals of Milan, Strasburgh, and Rouen; in England, at York, Lincoln, Ely, Salisbury, &c. The enrichments in the cathedral at Salisbury are of a very peculiar description, as will be seen by a reference to *plate* XL.

The organ-screen at York is, perhaps, the most exquisite piece of Gothic workmanship now in existence.*

There are very early traces of the application of plain plastering to Gothic buildings to be met with in Great Britain; one very old example may be seen at the Manor Shore, York, in the remains of St. Mary's Abbey, where it occurs that the plain panels of the groined roof have been covered with a coat of plaster; but England is indebted to the enterprising genius of Mr. Francis Bernasconi for the application of Gothic ornamental plastering to buildings of every description. He, under the auspices of the justly-celebrated James Wyatt, Esq. (the reviver of florid Gothic architecture in England,) Elliot, Porden, Atkinson, &c. has executed several works of great magnitude, among which may be particularly enumerated, Fonthill Abbey, the grand staircase at Windsor Castle, finished in 1801; Eaton Hall, the seat of Earl Grosvenor; and Taymouth Castle, the seat of the Earl of Breadalbane.†

* It was repaired with plaster, by Mr. Bernasconi, in the year 1804.

† The staircase at Taymouth Castle is the most magnificent Gothic staircase in Great Britain, it being 40 feet square, and 80 feet high; it was designed by Elliot.

As Joseph Bernasconi, the greatest Gothic modeller that ever lived, formed his taste from a shrewd observance of the embellishments of York Cathedral, we would most strongly enforce an acquaintance with the examples of York, as well as those of Ely, to future aspirants in this peculiar department in preference to any others in England.

As the cathedral at York will only be accessible to a few, Halfpenny's folio book of ornaments will be found of essential service.

We would also most particularly recommend to modellers, the study of the heads by Mr. Francis Bernasconi, finishing under the labels of doors and windows, and likewise those in other situations.

Of the Elizabethan Style of Ornament.

324. About the year 1560, a style of finishing of a very peculiar character, uniting many absurdities of design with great beauty of workmanship, and frequently astonishing ingenuity in some of its combinations, came into general use. The name of the original inventor of this style remains in mystery, but, on comparison, a strong resemblance between its outline and the Gothic of Salisbury Cathedral is observable, although there is a great difference in the projection and manner of finishing. It is obvious, from the numerous examples extant, that it arrived at its greatest perfection during the reign of Elizabeth, and was also generally practised in those of James and Charles the First.

Its parts consist of the interlacing of numerous small fillets in every imaginable form, with the frequent introduction of grotesque heads and small rosettes.

The finest specimens of this style may be seen at Longleate-House, near Salisbury, the seat of the Marquis of Bath; in Lord Holland's house at Kensington; in some of the halls in the Temple, London; and also on the exterior of Northumberland-House; but, perhaps, the best specimen is Queen Elizabeth's gallery in Windsor Castle, executed during her reign, the ceiling of which is literally covered with ornament. The chimney-piece in this gallery, together with several chairs composed of ebony, which were formerly removed to Hampton-Court, but, subsequently, placed in the corridor at Windsor, are complete chef-d'œuvres of this beautiful, though peculiar, style of embellishment.

Of the Old English Style of Ornament.

325. About the year 1630, under the auspices and from the designs of the celebrated Inigo Jones, the old English, or, as it is generally called, strap foliage, was introduced and much practised.

This style is of a very rich flowing character, abounding with splendid festoons composed of fruit and flowers, and also foliage springing from elaborately worked trophies and shields. It has been by some said to be a modification of the old Italian ornament, and indeed a great

similarity in design may be traced, by comparing its ornaments with those in the Architectura di Sebastian Serlio.

Albin's House, in Essex, the seat of Rutherford Abdy, Esq. which was executed from the drawings of Inigo Jones, is a very fine specimen.*

Of the Roman Style of Ornament.

326. The Old English manner of finishing, after some years, was superseded by one which participated a great deal more of the Roman character. It was brought to its greatest perfection in England, at old Buckingham-House, in 1703, which was at that time executed by Rose from the designs of the learned and accomplished John Sheffield Duke of Buckingham.

Many of the works of Sir Christopher Wren, and other eminent architects, are finished in this style.

The finest ancient specimens now extant are to be found in the three columns of the Campo Vaccino, the baths of Dioclesian, the frontispiece of Nero, and the pantheon, at Rome. The best examples in England may be seen in St. Paul's Cathedral and other churches in the metropolis, and also at Uxbridge-House, in Burlington Street, the residence of the Marquis of Anglesea.

The parallel of ancient and modern architecture by Monsieur Ronald Freart, Sieur de Chambray, which was translated into English by John Evelyn, in 1707, may be consulted with great advantage, as it contains many designs from ancient Rome, executed with a precision and beauty truly astonishing.

Amongst the moderns, who have most eminently contributed to the advancement and improvement of the Roman ornament, Bulliphant, Watling, Ash, Papworth, Finney, and Rothwood, may be enumerated. The Roman foliage of Bulliphant, for gracefulness of outline and delicacy of finish, has, perhaps, never been equalled; but the works of any of the above modellers may be profitably consulted by the aspirant to perfection in this manner of embellishment.

Of the Grecian Style of Ornament.

327. The Grecian style of decoration (which having been, as we before stated) greatly improved from the models of the Egyptians, began to arrive at perfection under the fostering care of Pericles, which period, including the reign of Alexander, must be considered as the climax of grace, elegance, and beauty, in Greece.

The enterprise of men of genius, amongst whom Stuart, Revett, and Cotterill, stand most conspicuous, who have travelled through Greece, and published the results of their researches, illustrated by copious drawings of buildings, with details of their various parts or

* The library is the best specimen, and is ninety-seven feet long.

ornaments, has accelerated an admiration of those magnificent displays of antiquity, and consequently the adaptation of Grecian architecture, both to ecclesiastical and domestic purposes.

Its most striking characteristics are great simplicity, chasteness, and purity of design, without that grandeur of effect so peculiarly belonging to the Gothic, and at the same time not admitting of so much diversity.

The prevailing ornaments adopted by the Greeks were the lotus and honey-suckle, which are most frequently applied to their friezes, but they are also often introduced in other situations. Their friezes are also charged with bas-reliefs, representing subjects from the heathen mythology and triumphal processions.

Besides the ornaments above alluded to, we have Greek ovolos, ogees, &c.; the former, being an imitation of an egg encircled by a band, is by some workmen called an egg-mould.

The finest examples of Grecian ornament in this country are the Elgin marbles, which were brought over by the Earl of Elgin, and whose name they have since taken. Stuart and Rivett's Atnens may also be consulted on this subject with equal advantage.

Of the French Style of Ornament.

328. In the reign of Louis XIV, a peculiar and fantastic style of ornament came into general use for the decoration of the interiors of buildings. It consists of a great profusion of foliage twisting round mouldings, and emanating from heads, animals, shells, shields, trophies, &c.; the line of the foliage throughout being invariably maintained with an exquisite degree of freedom and spirit.

The Italian stucco-workers, Catezi, Philip Danielli, and Franconi, being no doubt on their route through France to this country, struck with the beauty of this style, were the first workers of it to any extent in England, although, prior to their time, some small portions had been executed, as may be seen in the churches of St. Giles and St. Martin-in-the-Fields, London.*

Beautiful specimens of the works of the above mentioned stucco-workers are to be found in the county of Durham, in the banqueting-room and temple at Hardwick, and also in the castles of Bishop's Auckland, Lumley, and Hilton, executed about the year 1760.

This style for the last half century has been disused in England, but is now in a great measure revived through the instrumentality of those eminent architects, Sir Geoffry Wyattville and Benjamin Wyatt, Esq.; the former having applied it to the decorating of the drawing-room, library, and reading-rooms, at the royal residence at Windsor, and likewise to the ball-room, which is now in progress. The ball-room, when finished, will present the most splendid display of this style to be met with in Great Britain. The latter architect has m-

* The ornamental work in St. Martin's church was executed by Artezi, about the year 1726.

troduced it with great effect in the mansion which was built for the late Duke of York. The staircase in this building cannot be too greatly admired, not only for the workmanship, but also for its ample dimensions, it being 56 feet by 46 feet, and 73 feet high. The ornamental work is completely free from those absurdities so frequently complained of in a majority of the old examples, all its parts corresponding with each other, thereby not having the appearance of being *lop-sided*.*

We would most particularly call the attention of the ingenious to an examination of the specimens noticed above, as a careful investigation of their different merits will assist the student in the formation of his taste.

We would also recommend a reference to the folio work of La Porte, published in Paris at the period when French ornament was in the meridian of its splendour; the original sketches of La Fosse; the work by Swan; and last, but not least, the elaborately-finished prints by the justly-celebrated Gribelin, originally published by Bowles, in St. Paul's Church-Yard, but now only to be had in loose engravings, the work itself being now extinct. The plates by Gribelin are as useful to chasers in gold and silver, as they are to the ornamental plasterer, and are in themselves complete gems of art.

Having thus, we trust, given the young artist a clear and intelligible description of the different styles of ornament, we will next endeavour to give an account of the materials and compositions made use of for internal and external finishing, and also an explanation of the various operations and modes of performing them.

CHAPTER II.

Of the Materials and Compositions used in Internal Finishing.

329. Laths, which in general form the ground-work of all kinds of plastering, consist of thin slips of wood, which are nailed to ceilings and partitions of rooms, with a very narrow opening between each, for the purpose of receiving the coarse stuff or pricking-up coat. They are made of oak or fir, and are of various lengths, as three-foots, three-and-half, four-foots, and four-and-half, and are sometimes made of many other lenghts to suit particular purposes.

They may either be purchased by the foot, bundle, or load. They are also of different degrees of thickness, as single-laths, lath-and-half, and double-laths. Single laths are the cheapest and thinnest lath-and-half denotes one-third, and double laths twice the thickness of single laths.

* The interior of Apsley-House is also finished in this style.

The laths generally used in London are made of fir imported from Norway, the Baltic, and America, in pieces called *staves*. Most of the London timber-merchants are dealers in them, and there are many persons who confine themselves exclusively to this branch of trade, under the title of lath-renders.

330. Lime, which forms a most essential ingredient in all the operations of plastering, is prepared from two substances, viz. lime-stone and chalk, which are broken into small pieces, and piled in convenient layers, with coal, furze, or other fuel, in proper kilns, where they are kept for a considerable time in a white heat.

Bishop Watson found, by experiment, that, upon an average, every ton of lime-stone produced 11 cwt. 1 qr. 4 lbs. of quick-lime, weighed before it was cold; and that when exposed to the air, it increased in weight daily, at the rate of a hundred weight per ton, for the first five or six days after it was drawn from the kiln, owing to its gradual absorption of carbonic acid.

Great precaution ought always to be exercised in the choice of lime, particularly avoiding the stone of a hard nature, for if great care be not taken in the slacking, owing to the quantity of magnesia it contains, which being almost insoluble in water, it will eventually spoil the work, however great the pains which may have been taken in the finishing, by breaking out in ugly protuberances, called by the plasterer, blisters. The lime of Breedon, in Leicestershire, is found to contain half its weight of magnesia.

The principal portion of lime used in London and its vicinity is prepared from chalk, and the greater part of it is brought from Purfleet, in Essex; but for stuccoing and external finishing, in which strength and durability are required, the lime manufactured at Dorking is preferred. This useful article is sold at the wharfs about London, in bags, containing each one hundred pecks.

331. Sand, which is so material for the making of good mortar, ought always to be chosen of the sharpest description, of a consistency approaching to fine gravel, free from all particles of earth or clay, for on the purity and quality of the sand, the strength and durability of the mortar entirely depends.

332. Lime and Hair, or coarse stuff, is prepared in different ways, which must be determined by the quality of the materials.

When prepared from chalk or lime-stone of a weak nature, it is screened and prepared in the usual way, similar to common mortar, with the addition of hair from the tan-yards, and may be used a few days after its preparation; but when the lime-stone is of a hot or hard quality, it is not advisable to adopt this method, for if the stuff be used soon after its preparation, it will inevitably cause blisters in the work. The safest mode of preparing lime and hair, when the stone is of a strong nature, is by forming a pan or binn of a convenient size, perfectly water-tight, and about 18 inches in depth. A large tub must then be procured into which the lime, after having been well slacked must be put and mixed with a proper propor-

tion of water, and run through a sieve with apertures not exceeding a quarter of an inch, until the pan is filled, when the hair and sand must be added, the whole being well incorporated with a drag or three-pronged rake. There must then be a small hole made at a suitable height in the side of the pan, to allow the water to escape. After thus remaining until it be sufficiently set, it may be taken out of the pan and made fit for use by the labourers.

This composition is used for the first or pricking-up coat, and for the floating of ceilings and walls. It is also used for mouldings and cornices which require much stuff, in which case it is mixed with plaster of Paris.

333. Fine Stuff is commonly used for giving the last coat to the plain surfaces of floated work. It consists of pure lime slacked with a sufficient quantity of water, and well saturated. It is afterwards run through a fine sieve, and put into tubs in a semi-fluid state, where it is allowed to settle and the water to evaporate, when a small portion of white hair may be added, which will very much improve its quality.

334. Stucco, for inside walls, called trowelled or bastard stucco, is composed of fine stuff, above described, (omitting the hair,) and very fine washed sand well incorporated with it, in the proportion of one of the latter to three of the former. All walls intended to be painted or papered should be finished with this stucco; but for what is termed rough stucco, commonly applied to staircases, passages, and entrance-halls, a larger portion of sand ought to be used, and that of a much coarser quality.

335. Plasterers' Putty is prepared from unslacked lime, the process being performed by immersing the lime in water where it remains until it be completely dissolved; the liquid being then strained through a very fine sieve must be left in this state until set, when it is considered fit for use.

Putty is used in all the finer branches of plastering, as for the *setting* or last coats of soffits, and for the running of mouldings and cornices. When it is used for mouldings, it is mixed with plaster of Paris, which induces it to set quickly and become more dense.

336. Stucco, which was used by the old ornament-workers, is prepared in a very peculiar manner. It has, since the invention of casting ornaments in moulds, almost entirely fallen into disuse; however, it is but proper here to notice it for the benefit of the curious.

A sufficient quantity of fine putty being procured to complete the portion of work contemplated, some marble-dust, made very fine, or pounded alabaster, (and in some cases very fine silver-sand,) must be added. This mixture must be well chafed and spread over a brick-wall, in order to assist the co-operation of the water. After it becomes stiff, it must be taken from the wall, and well chafed with a wooden beater until it becomes tough; it must then be spread over the wall a second time, and the same process repeated, viz. chafing it well with the beater until it becomes plastic, when it is fit for use, and may be applied to the ornamental work after it has been first *boasted* with lime and hair.

This kind of stucco is sometimes mixed with a small portion of burnt plaster of Paris, prepared in the manner of lime, instead of being, according to the usual mode, baked in an oven, which prevents it from setting within twenty-four hours.

Many specimens of ornament worked with this composition by Durham, who was a pupil of Catezi's, may be seen in many parts of the north of England.

Stucco, used at the present day for the working of Gothic ornaments, such as bosses, spandrels, and corbels, is merely a simple mixture of putty, with silver or very fine house-sand.

337. Plaster of Paris, as it is commonly called, is the composition on which the plasterer materially depends for giving the precise form and finish to the decorative part of his work; by its aid he executes all the ornaments applied to ceilings and cornices, besides sometimes mixing it with his lime used in the finishing coat of the walls and ceilings of rooms, in cases of emergency, when time is of material consequence.

This composition is known amongst chemists, by the several names of sulphate of lime, selenite, and gypsum.

The property which plaster possesses, of setting into a compact mass when mixed with water, was, according to Herodotus, the Greek historian, well known to the ancients. According to his account, the inhabitants of Ethiopia had a peculiar method by which they preserved the remembrance of their deceased relatives. After having dried the body in the sun, they enveloped it in a paste of gypsum, and afterwards painted the likeness of the real figure on the encrustation with which it was covered.

The sulphate of lime is found in immense quantities in the hill named Mont Martre, in the vicinity of Paris, and hence its name, plaster of Paris. The stone from this place is, in its appearance, similar to common freestone, excepting its being replete with small specular crystals. The French mode of manufacture is by breaking the stone into small fragments, about the size of an egg, then burning it in kilns with billets of wood, until the crystals lose their brilliancy; it is afterwards ground with stones to different degrees of fineness, according to the different purposes for which it is intended. This kind of specular gypsum is found in great abundance in Russia, where it is said to be used in the windows of their cottages, as a substitute for glass.

The specific gravity of gypsum, or plaster of Paris, varies from 1.872 to 2.311., and, according to Bergman, contains 32 parts of lime, and 68 of acid and water, requiring 500 parts of cold, and 450 of heat, to dissolve it. In the process of burning, or calcination, it decrepitates, becomes very friable and white, and heats a little with water.

The plaster commonly used in the metropolis is prepared from a sulphate of lime, produced in Derbyshire, and called alabaster. It is brought to London in a crude state, calcined, and afterwards ground in a mill, when it is ready for use, being usually sold in brown paper bags, each containing about half a peck.

At Chelaston, near Derby, 800 tons are annually raised. It is also found in most of the cliffs in the Severn, especially at the Old Passage, near Bristol. There are also excellent

quarries near Rippon and Hull, in Yorkshire, great quantities being annually shipped from the latter place.

This mineral is much used in Derbyshire, for laying the floors of cheese-rooms, granaries, &c. After preparing it in the usual way, they mix it with water, and spread it on the floors about 2½ inches thick, which, when dry, forms a smooth surface and durable flooring, the whole expence not exceeding 1*s.* 6*d.* per square yard.

338. Paste Composition is a most excellent substitute for carving in wood, at much less expence, and may be very successfully applied to picture-frames, window-cornices, trusses, and brackets, or, indeed, to any ornamental work, which is afterwards to be painted or gilded, it being frequently used for the execution of the cornices and capitals of shop-fronts.

It is composed of—7 parts glue, 2 do. linseed-oil, 7 do. rosin.

The glue and linseed-oil must be first well boiled together, the rosin being bruised must be then added, and the whole stirred until they be completely incorporated. This mixture is poured into a small dam, formed of whiting, with which it is thickened until it comes to the consistency of baker's dough, it is then rolled out into flat cakes, and forced into moulds by means of a screw and lever-press.

The moulds used are either of wood, sulphur, or brass. Wood moulds are made by sinking the reverse of the ornament intended to be produced, in a piece of Turkey box, which process requires the greatest care and much practice to produce any thing perfect, but indeed wood-moulds are only suitable for the finest and smallest parts of embellishments.

Sulphur moulds, which are most commonly used, are formed from the clay model, by pouring liquid sulphur over it, having previously placed a fence of clay round the model, and oiled it with sweet oil. The sulphur-mould, thus formed, is trimmed and fixed in a block of wood or cast-iron. When the wood is adopted, a space is cut in the block sufficiently large to admit the mould, the interstices being filled up with liquid sulphur, thus keeping it securely in its place, for were it not for this precaution, the mould would be crushed to atoms by the action of the press the first time that an attempt was made to squeeze the composition into it.

Brass moulds are made by moulding the model with plaster of Paris, which inverse mould is sent to the brass-founder and by him moulded in brass, after which it is chased or riffled. It is necessary that brass moulds be bedded in wooden blocks, to protect them from injury.

339. Scagliola has, of late years, begun to be much practised in the interiors of the mansions of our nobility, and may be applied not only to columns and their capitals and bases, but also to the paneling of walls, &c.*

The formation of columns, &c., in scagliola, is a distinct branch of plastering. It was first invented in Italy, thence carried to France, and afterwards to England. For its introduction into this country we are indebted to Henry Holland, Esq., who was, for many years,

* A beautiful specimen of this style of paneling may be seen at the Marquis of Stafford's new house in St. James's Park.

the favourite architect of his late Majesty George III. He procured artists from Paris to perform works with this composition at Carlton Palace, some of whom finding a considerable demand for their productions, remained amongst us, from whom our British workmen learnt the art, and have since brought it to the greatest perfection.

Scagliola is a composition of plaster of Paris and eartny colours, or any colours which will withstand the action of an alkali. In its manufacture, the ground or predominating colour is first mixed to the desired tint, and the other colours intended to be introduced must be mixed separately with a portion of clear size, and a little spirits of turpentine, to facilitate the drying.

If, in the marble intended to be imitated, the colours blend gradually into each other, as in sienna and the others generally executed, the imitation must be formed while the colours are in a soft state, by putting the ground mixture into a large trough, and adding the different colours in a proportion and a taste which can alone be acquired by experience.

If, on the contrary, the distinction between the colours is strongly marked, the secondary colours must be allowed to set nearly hard, broken into small pieces, and added to the ground mixture, which must be kept in the trough in a soft state, as before mentioned.

Manner of forming Columns or Pilasters in Scagliola.

340. When the architect has furnished the drawing exhibiting the diameter of the shaft, a cradle is made of wood about $2\frac{1}{2}$ inches less in diameter than the projected column. The circumference of this cradle being lathed with double laths, as in common plastering, must be covered with a pricking-up coat of plaster, gauged with very thin size, in order to harden it.

The pricking-up coat, after being completely set, must be well soaked with water. The composition must be then taken from the trough, flattened into cakes about eight inches square, applied to the column, and well beat on with a wooden beater and small gauging trowel. In this state it must remain until perfectly dry, when the protuberances may be taken off with a plane. The column must then be put in the lathe and turned to the size required. This operation being finished, it will have a porous appearance, which must be obviated by the application of a thick wash, and scraping it with steel scrapers, until it assumes the surface of real marble, when it will be fit for polishing, which must be effected by first using pumice-stone, at the same time cleansing it with a wet sponge, and afterwards with Tripoli powder and charcoal. After going over the whole with a piece of white glove-leather, dipped in a mixture of Tripoli powder and oil of olives, the process must be finished by the application of pure oil.

White Scagliola is simply a mixture of plaster of Paris and mineral green, the manner of using it being the same as above described.

CHAPTER III.

Of External Compositions.

341. Within the last fifty years, considerable improvements have been made in the art of Plastering, by the invention of various compositions for the covering of the exteriors of buildings, such as Roman Cement, Terra Cotta, Mastic, and Bailey's Composition.

These compositions are susceptible of being applied both to the finishing a plain face, to be jointed to imitate stone, and also in the formation of ornaments of every description.

Before the period alluded to, the application of cements to the exteriors of buildings was unknown; but the facility of their adaptation, on account of their cheapness, has tended greatly to foster the art of design, and produce a diversity of architectural display which heretofore was never dreamt of, as an inspection of Regent Street, and the terraces in the Regent's Park, will fully substantiate.

The careful study of the antique examples of architecture, both in Greece and ancient Rome, has also acted as a powerful stimulus to the promotion of the art of design, as well as ornamental plastering, more particularly in the getting up of Greek and Roman capitals, the former of which were, until within the last few years, scarcely known in this country, and the latter have been most amazingly improved by means of a reference to the casts procured from the originals now extant.

The invention of compositions has, no doubt, been facilitated by the great scarcity of good stone in the southern parts of Great Britain, a misfortune which appears very evident in comparing the streets and public buildings of the metropolis with those of the Scottish capital.

342. Roman Cement, which is by plasterers, for the sake of brevity, called *Compo*, was first introduced to public notice by the late James Wyatt, Esq. It was originally known as Parker's Patent Cement, and sold by Messrs. Charles Wyatt and Co., Bankside, London; but there is now a much superior article prepared from a stone discovered by William Atkinson, Esq., on the estate of the Earl of Mulgrave, at Sandsend, near Whitby, in Yorkshire, and which is now universally known by the appellation of Atkinson's Cement. The latter is certainly, in the first instance, a little higher in price, but it will bear a great deal more sand than the former; is of a more delicate stone colour, and for situations constantly exposed to the action of water, not to be surpassed by any cement now in existence.

Roman cement is prepared from the kind of stone, called clay-balls, or septaria, by being, after the manner of manufacturing plaster, first broken into pieces of a convenient size, slowly

calcined in kilns or ovens, and afterwards ground to a fine powder, and put into proper casks, great care being taken to preserve it from damp.

Two parts of this composition, with three parts of clean grit-sand, will form a very durable substitute for stone. In selecting the sand, great care must be taken to procure it possessing qualities of a sharp and binding nature, and free from clay or mud; if it cannot be procured free from these, it must be washed until perfectly clean.

After the walls intended to be covered have been well soaked with water, the cement must be prepared by the hawke-boy on a stuff-board made for the purpose, adding as much water as brings it to the consistency of paste, but no more must be mixed than can be used in ten minutes. It must be laid on with the greatest possible expedition, in one coat of three-quarters of an inch in thickness, and, after being well-adjusted with the floating-rule, the hand-float must be incessantly used to bring it to a firm and solid surface before it sets, which takes place within fifteen minutes, if the cement be good.

When the work is all finished in the stuccoing, viz. after it has been drawn and jointed to imitate well-bonded masonry, it may be coloured with washes composed of five ounces of copperas to every gallon of water, mixed with a sufficient quantity of fresh lime and cement, adding the colours necessary to produce an exact imitation of any particular stone which may be required. When this mode of colouring is executed with judgment, and finished with taste, so as to produce a picturesque effect, by touching the divisions with rich tints of ochre, umber, &c., it is with difficulty distinguished from real stone.

It has been attempted, and in some cases very successfully, to produce ancient Gothic ruins in cement, and although to consummate the deception, great skill and judgment are required, yet we have no doubt that, by paying proper attention to the style of architecture, as well as the manner of colouring, imitations of this kind might be carried to great perfection.

343. Terra Cotta, or Artificial Stone, is an excellent as well as durable composition made use of at the present day very advantageously for all kinds of exterior decoration. It is a compound of pipe-clay, stone-bottles, glass, and flint, well pounded together, and sifted through a very fine sieve, a small portion of silver-sand being afterwards added. The above ingredients must first be well mixed in a dry state, and then water added to reduce them to the pliability of modellers' clay. The mixture, thus formed, having remained in this state for two or three days, must be beat or tempered in a similar manner to modelling clay, after which it is fit for use.

Manner of working Terra Cotta as applied to Capitals.—The bell, or core, must be prepared not more than two inches and a half thick, the stuff of which it is composed being of a coarser nature than that used for its embellishments. After the ornaments, as the leaves, volutes, &c. have been modelled, they must be moulded in plaster, and squeezes of artificial stone taken from the moulds, well cleaned up with appropriate tools, and fixed to the bell. It is necessary, when the ornaments are fitted, to bore two or three holes, three-quarters of an

inch in diameter, on those parts of the bell where the enrichments are to be placed, in order to let the damp air escape in the process of burning.

To fix the ornaments, procure some of the dry composition, and let it remain in water about one day, then take out the portion that remains at the bottom, which being well chafed on a hawke, composes the stuff for fixing.

After the bell and the back of the enrichments have been well roughed, a little soft stuff is rubbed on each, and the ornament attached to the bell in the usual way.

The capital being then in a fit state for drying, must be left in the open air for that purpose, and, when thoroughly dried, placed in the kiln, which is composed of the same materials as a common oven, but of a somewhat different construction, as the flue must extend entirely over the coved ceiling of the kiln, and be perfectly clear of the ornament.

In the burning of Terra Cotta, it is necessary to commence with a very slow fire, gradually increasing it for the first week, after which a brisk fire must be kept up for three days and nights without intermission. The front of the kiln must then be closed with an iron plate to prevent the ingress of the atmospheric air. Having remained three days in this situation, it is considered sufficiently burnt, and the kiln must be gradually opened, as the sudden admission of the air will cause the ornaments to crack or splinter.

Method of Moulding Terra Cotta.—The models being executed in clay, as is usual in modelling plaster-ornaments, they must be moulded in the same manner as figures and busts, with this difference, that the clay must not be oiled, nor the joints of the plaster-pieces which compose the mould. Instead of oiling the model, it is washed all over with pure water, when the moulder may commence his operations. The various joints of the plaster-pieces in the mould must be touched with a small brush containing a little liquid clay (instead of oil, which is the general method,) great care being taken in the formation of the different joints, as the pieces cannot be taken from the model to be cut and fitted, but must all be brought to their particular shapes while they remain on it. When the sufficient number of pieces are made, so as to completely envelop the model, a case of plaster must be put over the whole. In taking the pieces from the model, it is requisite to soak the whole in water, in order that they may *leave* the more readily, which being done, the mould must be well washed and put into the case, and gradually dried in the air, when it will be fit for use without the process of seasoning in oil, as is customary in casting in plaster from a plaster-mould.

Manner of procuring Impressions from the Mould in Terra Cotta, commonly called Squeezing.—The mould being thoroughly dry, the workman must take a little of the finer stuff in his hands, and press a thin coat over the whole of the face of the mould, adding on the back, that of a coarser quality, rubbing in small portions at a time, so that the ornament may be firm and solid. Immediately after squeezing, the ornament must be taken from the mould, cleaned up, and fixed in its place. When the mould has been used two or three times, it is liable to become damp, which prevents the impressions from *leaving* expeditiously; in this case, for

the purpose of destroying its adhesiveness, dust a little very finely sifted flint-powder into the mould.

These methods of moulding and casting may be judiciously applied not only to capitals, but also to all kinds of work in this composition, such as coats of arms, vases, fountains, figures, and busts, always taking the precaution never to allow the substance of artificial stone to exceed two inches and a half, for any greater thickness will be liable to injury in the burning.

344. Mastic, is an external composition possessing peculiar properties, which, in some cases, render it superior to Roman cement, having the power of resisting heat and adhering to iron, copper, and even glass, with equal tenacity.

It is generally applied to the exteriors of mansions, but it may also be very beneficially used for laying the floors of halls, kitchens, &c.*

This composition was first introduced into England from France by Hamlin, but is now sold by the sole manufacturers, Messrs. Francis and White, at Nine Elms, near Vauxhall Bridge. It is composed of pounded stone, silver sand, litharge, and red-lead, and when manufactured has the appearance of very fine sand. The manner of working Mastic is entirely different from that of Roman Cement.

To one cwt. of mastic add one gallon of linseed-oil, and let them be well incorporated by the labourer, which must be effected by treading them together with the feet until the amalgamation is complete, which may be easily ascertained by smoothing a portion of the mixture with the shovel, should any bright spots be observable, the treading must be again and again repeated until they completely disappear, when it is considered fit for use.

Manner of using Mastic.—The joints of the brick-work being well cleaned out, the work must be correctly plumbed up by means of flat-headed nails, and screeds for the guidance of the floating-rule formed with Roman cement, and kept about one inch in breadth. This being done, the bricks must be well saturated with boiled linseed-oil of the best quality, and the mastic laid on with the hands, assisted occasionally by the laying-trowel, until the space between the screeds be covered to the thickness required. The floating-rule is then passed carefully over the work, and when the space between the screeds is sufficiently filled up, it must be floated with a hand-float, composed of sycamore or beech, until it assumes the same appearance as highly polished stone. Thus a space of large dimensions must be followed up until the whole be completed, when the screeds must be cut out, their places filled with mastic, and compactly hand-floated into the rest of the work.

These directions will be found suitable for large surfaces, but where windows frequently occur, it will be necessary to attach rules, about three-eighths of an inch in thickness, to the sides of the windows, the reveals being formed by applying a set square to the window-frame and rules. The rules being eventually taken down, the nail-holes must be filled up and adjusted with the hand-float.

* The best specimen of mastic-work in London is the house of the Duke of Clarence, in St. James's.

In order to run mouldings with mastic, a mould of wood must be cut, in every way three-eighths of an inch less than the intended moulding. The moulding, being dubbed up with broken tiles, must be first run out with Roman cement, and afterwards with mastic, the mastic-mould being cut to the exact size, and bevelled, the edge being mounted with brass or iron. All ornaments executed in mastic must be cast in plaster-moulds, similar to those used in figure-casting, only that they must not be seasoned with oil, but used in their dry state, especial care being taken to preserve them from all moisture or particles of mastic. The ornaments must always be taken out before the mastic is set, and a perfectly dry polish kept on the face of the moulds by frequently rubbing them with tow or linen rag.

Manner of fixing Modillions, &c. on Soffits.—Dovetail a hole rather smaller than the size of the modillion, penetrating as far as the brick-work; having marked the size of the aperture on the top of the modillion which goes next the soffit, fill it with nails, then gauge some Roman cement, with which fill the hole. While the cement is in a soft state, fix the modillion in its place with the nails in it. All small enrichments may be easily fixed with white lead.

Manner of laying Floors with Mastic.—The ground-work being completely dry, the space to be covered with mastic must be laid by the bricklayer with bricks edge-ways upwards, and completely level. The brick-work being entirely dry, it must be well cleaned and saturated with boiled linseed-oil. Screeds must then be formed with Roman cement at the places most convenient for the working of the floating-rule, levelling from the slab that goes round the room. These screeds must be one inch in breadth, and a sufficient thickness to allow a coat of three-eighths or half an inch of mastic. All the screeds being formed, the space between them must be covered with mastic, and the superfluous stuff taken off with the floating-rule, which must be frequently wiped with a cloth to prevent it from sticking to the work. It must afterwards be floated, the screeds cut out, and their places filled up in the usual way.

345. Bailey's Composition is a most valuable invention, of recent date, and may be used with great advantage in various situations, without being at all injured by the severest winter. The exteriors of many of the public buildings in the metropolis are covered with this composition, amongst which is the Colosseum in the Regent's Park.

It is simply a mixture of lime and sand, the strength of the lime being preserved by the peculiar manner in which it is prepared. In its manufacture, chalk should never be used; it ought always to be made from lime-stone or carbonate of lime.

The lime, being taken before being slacked and ground to a fine powder, must be placed in iron-bound casks to prevent the admission of air or damp. When used, it must be mixed with one-third its quantity of sharp river sand, the manner of working it being the same as that of Roman cement.

CHAPTER IV.

Operations, and Modes of performing them.

346. Lathing, which is the method of preparing walls for the reception of plastering, consists in nailing thin slips of wood, of divers lengths, on ceilings and walls. The nails used in lathing are of two sorts, viz. wrought and cast-iron: the wrought-iron nails are much to be preferred. The cast-iron ones may be employed for common purposes, but cannot be used with any degree of safety, when the joists of the building are composed of oak. For stoothed walls or partitions, the lightest or single laths may be used, but to ceilings, or any description of work requiring strength, double laths ought always to be applied.

After having determined the size of the ceiling, or walls, the laths whose lengths best suit the spaces between the joists must be chosen, and the nailing so managed, that the joints be as much broken as possible, as paying attention to this will strengthen the plastering laid thereon by giving it a firmer key or tie.

347. Pricking-up, or first coating, is performed by spreading a single coat of lime and hair upon a ceiling, or partition of an equal thickness in every part; this being completed, the surface is well scratched with the end of a lath, in order to give a key or tie to the floated coat which is to follow.

348. Laying, which is the cheapest manner of plastering, consists in laying on a single coat of coarse stuff entirely over a wall or ceiling, taking care to keep it even and perfectly smooth throughout.

349. Two-coat work, is also another cheap manner of plastering, principally practised in the North of England, in performing which the pricking-up coat must only be slightly scratched with a small broom prepared for the purpose, and then a thin coat of finer lime and hair spread over, which must be made regular with the derby, and afterwards smoothed with the setting-trowel.

350 Floating, is the laying on of the coat of plastering (on all work intended to be well finished) immediately following the pricking-up coat. In floating ceilings the following directions must be observed:—

The pricking-up coat being sufficiently dry, and the projection of the cornice ascertained from the drawings, and marked on the ceiling, a screed must be formed about eight inches wide at this projection, perfectly straight and level. This is effected by driving in a nail at the projection of the cornice, allowing it to protrude sufficiently from the pricking-up coat to allow the usual thickness of floating, which is generally about half an inch, a convenient level being

then procured, another nail is put in at its extremity and adjusted until it exactly coincides with the first nail. This process being followed up all round the ceiling, other nails are put in directly opposite to those already mentioned, and about seven or eight inches from them, being at right-angles from the walls, and made exactly level with the former ones, by the assistance of a small triangle. A portion of coarse stuff must then be applied between the nails, and with a short float bearing on the two nails made perfectly straight, which forms what the plasterer terms a dot. These dots are formed at each length of the level, which is commonly 10 or 12 feet. When the dots are sufficiently set, the spaces between them are filled up flush with coarse stuff, and finished with the floating-rule, which must be about two feet longer than the level, so that it may bear well on each of the dots. This being finished, it forms a perfect screed round the whole of the ceiling, and serves for a guide in the floating of the inner part of it. This screed being dry, others are formed about eight feet apart, parallel to the ends of the room, which being set, the spaces between them are filled up flush, and made even with the face of the screeds.

The floating is thus finished, by applying the floating-rule on the screeds, and moving it backwards and forwards until the whole of the floating is completely level with them. The ceiling is then gone over with the hand-float, making good any deficiencies that may appear in the floating, by adding a little soft stuff, until the whole is a perfectly smooth and compact mass. The same methods apply to the floating of walls, with this difference, that the screeds must be plumbed from the wood-grounds at the bottom of the room, instead of being levelled as is the case in ceilings.

351. Setting.—After the floating has remained until it be quite firm and solid, which requires it to be nearly half dry, it is covered with a thin coat of putty, (mixed with a little fine sand, and sometimes a little white hair,) called setting. In cases of emergency, the putty is gauged in small quantities at a time, by adding to it about one-third of plaster of Paris, which causes it to set more quickly. The floated work must not be allowed to get too dry before the setting is applied to it, otherwise there is a probability of its cracking and eventually peeling off, thus giving the ceiling an unsightly appearance. But cracks in ceilings may arise from the laths being too weak, or from too much plaster being laid on, or from strong laths and too little plastering. Floated work, executed by a judicious workman, the materials being good, and the lathing properly attended to, no fears need be entertained of its cracking without the shrinking of the timbers.

352. Trowelled Stucco is a very neat mode of finishing, much used in drawing-rooms, dining-rooms, libraries, &c. Trowelled stucco is worked on a floated ground, the floating being nearly dry before the stucco is laid on. When the stucco has been prepared in the manner we have described under the head of Materials, it is beaten and tempered with clean water, until it is about the consistency of thin paste, when it is considered fit for use. The stucco being thus tempered, must be spread upon the ground prepared for its reception, about

one-sixteenth of an inch thick, by the aid of the largest trowel, as even as possible, and afterwards adjusted with the hand-float, which is a piece of deal, half an inch in thickness, about nine inches long, and three inches and a half wide, planed smooth, with a handle attached to the upper side to enable the workman to move it with facility. When a convenient portion of the work has been so spread, the plasterer, with a brush which he holds in his left hand, sprinkles a small portion of the stucco with water, and follows this operation by rubbing it with the hand-float, alternately sprinkling it with water and applying the hand-float, until the whole is reduced to a compact surface. In order to make it more complete, the same operation is again repeated; after which it is sprinkled with water, and smoothed with the setting-trowel, and, finally, brushed repeatedly in various directions with a dry stock-brush until it becomes quite smooth. The water has the effect of hardening the face of the stucco, so that, after being well hand-floated and finished with the setting-trowel and stock-brush, it feels to the touch as smooth as glass.

Walls intended to be painted or coloured are always finished with this kind of stucco.

353. Stucco for Paper, is prepared with a less portion of sand than the trowelled stucco, and is merely skimmed on the floated work, and polished by the assistance of water and the setting-trowel.

354. Rough Stucco, is generally applied to staircases, passages, and entrance-halls, and is worked in a different manner from the two preceding. It must be mixed with a much larger portion of sand, (even as much as the putty will bear), and that of a coarser quality than that used for trowelled stucco.

It is also worked on a floated ground, which should be taken in a half-dry state, and a thin coat of stucco spread over it with the setting-trowel, and subsequently gone over with the hand-float, adding stuff to fill up any defects which may occur. This stucco is also sometimes floated on with the derby, and afterwards with the hand-float, which is the best method, as it renders the surface of the work more regular. It is then hand-floated in the manner described for the trowelled stucco; but, in order to raise the grit of the sand more effectually, the hand-float must be covered with a piece of felt. It must be carefully hand-floated three times over, and instead of being smoothed, must be left rough from the hand-float, which gives the entire surface of the work the appearance of stone. When great care has been taken in the finishing of this peculiar stucco, it has a very beautiful appearance, and may be jointed to imitate well-bonded masonry.

355. Rough-Casting, is an outside finishing, which is performed by first giving the wall intended to be rough-casted a pricking-up coat of lime and hair, upon which, when tolerably dry, a second of the same material must be laid. As quick as the second coat is finished, a second workman follows the other with a pail of rough-cast, which he throws on the new plastering, in small portions at once, by means of a trowel prepared for the purpose, composed of a thin piece of sheet-iron, about seven inches long and five inches wide, with a wooden handle attached to

it. The materials used for rough-casting are fine gravel well washed, until completely free from all particles of earth or clay, mixed with pure lime and water, until the whole is in a semi-fluid state.

Plain and Ornamental Cornices.

356. In describing Plain Cornices, and the manner of their formation, it will be necessary, for the sake of perspicuity, to divide them into two distinct heads, viz. straight and circular: the latter requiring a different process, and more labour in the execution of it.

Plain Straight Cornices.

357. Previously to commencing the operation of forming the cornice, it should invariably be the practice of the plasterer to examine the drawings, even before the preparation is made for the pricking-up coat, as, when it happens that the projection of the cornice exceeds seven or eight inches, it is necessary to take a preliminary step, called bracketing, which consists of fixing pieces of wood, about an inch thick and a foot apart, all round the angle of the room where the cornice is to be formed.

The form of the bracket is obtained from the section of the cornice on the drawing, taking the precaution to allow an inch back from the line of the cornice for necessary stuff required in the formation of the members. On these brackets laths are fastened, and the whole covered with a coat of coarse stuff, which must remain until it be perfectly dry before the operator commences the formation of the cornice upon it. When the cornice has been so far forwarded, a mould must be made from the drawing to the profile or section of the cornice, exactly representing all its members. These moulds are either made of wood, copper, or iron. When wood is used, sycamore is found best adapted for the purpose, but beech, and other hard woods, are sometimes used. Wooden moulds are generally employed when there is only a small quantity of cornice to be done, but when there are many rooms to be embellished with the same pattern, copper or iron moulds are most preferred, they being more durable than wood, and the plasterer is enabled to make better work with them, as they tend to make the arrises, in particular, more sharp and clean.

358. In the making of iron or copper moulds, it is necessary to cut the profile of the cornice in a piece of pasteboard, which must be attached to a piece of the metal of sufficient size, and after the superfluous iron or copper has been removed with a pair of large shears, the members must be all exactly formed by the assistance of files of various degrees of fineness. This being completed, the profile, so cut, must be inserted in a piece of deal about half an inch thick, leaving about a quarter of an inch of the metal protruding from the wood, which must be levelled away, so as not to clog the mould during the process of running.

Another mould is also sometimes used, called the coarse stuff mould, which is employed in forming the cornice in coarse stuff previously to its being finished with putty and plaster of

Paris. This mould is traced from the other by keeping the line one-eighth of an inch within the other, so as to allow the necessary thickness for the fine stuff. The coarse stuff mould may be formed entirely of wood, and must be screwed to the side of the fine mould, and used in that manner until the cornice be formed in the coarse stuff; it is then taken off, and the cornice finished with the iron or copper mould.

The cutting of the moulds being completed, preparations are made for (as it is technically called) running the cornice.

The ceiling and walls having been antecedently floated, in the manner before described, the projection of the cornice must be marked on the ceiling, and also its encroachment on the wall. At each line of projection, on the ceiling, narrow screeds must be made with a very thin coat of strong gauged fine stuff, and made perfectly smooth with the floating-rule. In the making of these screeds, much care must be taken, as the correctness of the cornice in a great measure depends upon the precaution used in their formation. These preliminaries being gone through, the mould is applied to the angle, and its encroachment marked upon the wall, and a straight line drawn all round the room, which serves as a guide for fixing the running rules, which consist of pieces of wood about three inches wide, and half an inch thick, nailed upon the line (which has been drawn round the room) for the purpose of directing the mould in forming the cornice. This being done, the cornice is considered ready for running, which process requires two workmen,—one to lay on the stuff, and the other to work the mould.

The hawke-boy commences gauging the coarse stuff, which, at first, must be gauged very strong, gradually making it weaker until the cornice is full. The stuff being properly gauged, one of the workmen takes a portion of it on his hawke, and plasters a part of it on the place where the cornice is to be; the other workman then begins, by moving the mould backwards and forwards, holding it firmly to the ceiling and wall, thus removing the superfluous stuff. This operation is continued until the cornice is as perfectly formed as it is possible with the coarse stuff. This being done, the putty and plaster are then gauged, and the same process gone through as in the coarse stuff, using the fine mould, and adding gauged stuff until the exact contour of the cornice is formed.

When the projection of the cornice is very great, it is requisite to have small moulds to run the lower parts of the cornice, as the large mould will run no further than the square of its projection.

The mitres, internal and external, as well as breaks, or small returns, are afterwards worked in by hand with small tools for the purpose.

Circular and Elliptical Cornices.

359. Circular and elliptical mouldings require a great deal more labour than straight ones, but the principle on which they are executed is in every way similar, excepting that when they

are circular, they must be run from a centre, by means of what is termed a gig-stick,* to which the mould is attached; a hole being bored in it exactly to the radius, which fits to a pin placed exactly in the centre of the circular moulding.

When the mouldings are to describe an ellipsis, the most correct method is to run them from a trammel, such as is used by the carpenter.

Mouldings belonging to Groin Ceilings, commonly called Ribs.

360. The most approved method of forming the ribs on groined ceilings, now in practice, is, in the first place, to level the springings of the mouldings at the intersections, and then procure what is called an intersection-board, which must be fixed exactly at the termination of the mouldings on the wall, and perfectly level. The intersection-board must have the plan of the mouldings marked on it, and apertures pierced in it, coinciding exactly with the centre of each of the mouldings, for the reception of what is termed the horse, which serves for the mould to run on.

The horse consists of a stout piece of wood one inch and a half in thickness, got out exactly to the curve of the moulding intended to be run, sufficient allowance being made for the mould to move between the upper part of the horse and the ceiling, so that, when finished, the moulding may stand completely clear of the horse. After the horse has been properly fixed at the bottom, in the aperture made in the intersection-board, and at the top, at the crown of the arch, by means of an apparatus of a rectangular shape, of sufficient capacity to receive the end of the horse. This apparatus is generally composed of iron, of sufficient strength, with a screw inserted in the upper end of it, by which it is screwed into the ceiling to the height required. This being effected, there must be a hole pierced in each side of the apparatus, through which screws must be put, that come in contact with the horse, which serve to steady it when it has been fixed in its proper place in the apparatus and in the intersection board at the bottom.

The mould being cut in the usual way, must have two pieces of board attached to the bottom of it, at right-angles to each other, so that they may fit the horse in the process of running; the upper piece, attached to the mould which goes on the horse, may be three inches wide, and the lower one six inches, and of equal lengths, viz. about eight inches, or longer or shorter, in proportion to the size of the moulding.

The operation of running the moulding then commences, and is performed in every way similar to that described for cornices, except that the finishing coat must be fine stucco, (putty mixed with fine sand,) which must also be gauged and well incorporated with plaster of Paris, which gives to Gothic mouldings more the appearance of stone, which the plasterer frequently endeavours to imitate in this peculiar style of architecture. This kind of stucco possesses another signal advantage, as it has the property of making the mouldings much stronger than

* The gig-stick, in some of the northern counties of England is called a trainer.

if they were done with putty without sand. It is here worthy of remark, that the mould for running the ribs must be contrived so that it leave on each side of the upper part of it, at the extreme termination of the moulding, about one inch and a half of additional stuff, which will form a ground for floating in the plain spaces which compose the panels between the ribs. These spaces, after the ground is formed on each side of the moulding, are floated in with coarse stuff, by the assistance of floating rules of such lengths as may suit the dimensions of the panels, and finally finished with the hand-float.*

Intersections which terminate either on Corbels, or on the Capitals of Columns.

361. In the formation of intersections terminating either on corbels or capitals of columns, some difficulties are to be encountered, particularly when the room is of an oblong shape, as the arches then become of various spans, consequently altering their curves, and preventing the different members of the moulding from forming a regular mitre at the intersection; but, where circumstances will admit, these difficulties may be easily obviated, by having the intersection-board of a circular plan, and so contriving the curves of the arches, that they may be all of the same shape until they come directly over the intersection-board, gradually easing them off as they approach the extremity at the top.

In ceilings where the ribs are very numerous, and of various curves, the two following methods may be advantageously put in requisition for forming the intersections. First, as the moulding, as it approaches the intersection-board, is consequently curtailed, the large mould will not run it down to its extremity, it then becomes necessary to procure a smaller mould, in which the most prominent part of the moulding, or what is technically called the nosing of the moulding, is only formed. With this small mould, the most prominent member of the rib is continued down to the intersection-board at each corbel or capital, the joinings to which, and to the moulding at the place where the larger mould left off running, is made good by hand.

The second method is by procuring what the plasterer calls a cylinder, formed of wood, and the concave surface of which must exactly coincide with the back-ground of that portion of the moulding which occupies the space from the top of the intersection to the intersection-board, and also of sufficient width to allow the nosing of the moulding to be run upon it. The face of the cylinder thus forms the ground-work of the intersection, and being well oiled with sweet oil, a sufficient number of lengths of the nosing is run on it to complete the intersection. The cylinder being well oiled, the pieces are easily taken from it, and fixed in their proper situations with a portion of pure lime mixed with a small quantity of hair and sand, and well gauged with plaster of Paris, the intersection-board serving as a guide at the bottom, and the larger part of the moulding at the top, after which the joints are finished by hand.

* It is perhaps necessary to observe to the inexperienced, that the panels between the ribs of groined-work are invariably straight lines, excepting when the work is on a circular plan.

The mitres of the mouldings which occur at the crown of the arches or centres of the ceilings are executed with the assistance of joint or mitre rules, but, in most cases, they do not require so much nicety, being either covered with bosses, or flowers of various sorts of foliage.

Enriched or Ornamented Cornices.

362. Enriched cornices are executed in the same manner as plain ones, excepting that the mould must be so constructed, that, in running the plain parts, it leave indents or sinkings for the reception of the ornaments.

The formation of ornamented cornices presents a grand field for displaying the taste of the plasterer; and in the selection of ornament for this purpose strict regard ought always to be paid not only to the style, but also to the order of architecture to which it is applied, as nothing can appear more absurd than the loading a cornice indiscriminately with ornaments, which in no way coincide with the finishing of the other parts of the room.

The enriched cornices most generally executed at the present day may be divided into the four distinct heads of Grecian, Roman, Gothic, and French.

Grecian Cornices.

363. Grecian cornices are commonly decorated with friezes of various descriptions, together with ovolos, ogees, beads, frets, &c. What is technically called the honeysuckle frieze, from the supposition that the ancient Greeks had the first idea of its form from nature, is most frequently employed. For the sake of diversity, the honeysuckle and lotus are sometimes alternately executed on the same ground.

These friezes are modelled to various sizes, according to the magnitude of the buildings for which they are intended. The most convenient sizes for internal practice are from 6 to 15 inches in width.

Roman Cornices.

364. As we have before observed, there can be no doubt that the primitive ideas of Roman Cornices were copied from the Grecian buildings, and afterwards much improved by the addition of a great variety of embellishments of a flowing and elaborate description.

The Roman Doric cornice, when executed complete, has its characteristic ornaments, such as the guttæ or drops in the soffit of the corona, and also the triglyphs and metopes, generally charged with trophies of war, the skulls of oxen, &c.

Ionic cornices have frequently blocks or modillions, introduced into them, similar to those of the Corinthian, but of a plainer description.

The Roman Ionic frieze is sometimes embellished with festoons of flowers, supported by figures of children, as is the case in the frieze of the Temple of Fortuna Virilis, at Rome.

The Corinthian cornice is considered the most beautiful and delicate in its enrichments, as may be seen in our plate of Roman ornament. It consists of richly moulded reversas, ogees, modillions, &c., with their attendant coffers and roses. Sometimes (but that very rarely) the frieze is filled with rich winding foliage, a beautiful example of which may be seen by a reference to a work on ornament, published by Mr. Tatham, in which is a frieze from the Villa Aldobrandini, near Rome, where it is executed in white marble in high relief.

Of the Composite cornice, it is unnecessary to give a detail, as it is almost in every respect the same as the Corinthian, the entablature being the same, and the only difference between the two orders being in the volutes of the capital.

Gothic Cornices.

365. The forming of Gothic cornices in decorative stucco has, within the last half century, been carried to great perfection, but when we consider the vast source from which embellishments may be derived, we are led to conceive that by closely studying the old examples, many improvements may yet be made in their execution.

The principal features of Gothic cornices are very deep hollows, which are generally filled with spaced ornaments, that is, enrichments placed at a short distance from each other, having a plain space between them, or by continued and running ornaments composed of the acorns and leaves of the oak, the grapes and leaves of the vine, the leaves of the hop, thistle, &c. with the introduction of apes, squirrels, &c. peeping through the foliage.

French Cornices.

366. During the reign of Louis XIV. what are now called French cornices were executed to a great extent in France, and partially in England, but they have of late years been revived, and, when designed in strict accordance with this peculiar style, have a splendid and most magnificent effect.

These cornices, in general, consist of a large cove, with fully-enriched ovolos at its upper and lower extremity; the cove being always charged with luxuriant foliage emanating from a grotesque head, a part of the human figure, a large shell, or a beautifully-ornamented shield, with scrolls combining themselves with its outer edges.

An embellishment adapted for a cove may be seen by consulting *fig.* 1. in our plate of French Ornament. *Fig.* 6, also displays the angle of the upper part of a cornice in this taste.

Working Ornament by Hand.

367. The forming of ornaments of every description in their proper places, by means of suitable tools, commonly called "Hand Ornament working," is at the present day but partially practised, having been, in a great measure, superseded by the invention of cast-work; but, notwithstanding, we think it necessary to advert to it.

In working ornament, according to the method practised by the old Italian stucco-workers, it is necessary, in the first place, to draw the design of the ornaments, either in the cove or whatever situation they are intended to fill; the foliage, shields, trophies, fruit, flowers, or whatever it may be, must then be *boasted*, or got out in the rough, with gauged fine stuff, which is afterwards followed up by a thin coat of the kind of stucco, which we have described in our account of materials, under the head of "Ornament Stucco," which must be worked into the proper shape, and finally finished with the assistance of small steel tools of various sizes and patterns.

When the ornaments are intended to have a great emboss or projection from the ground, long nails, with tarred twine twisted round them, for the purpose of making the stuff adhere more closely, must be driven into the timbers; and in the formation of festoons of flowers, &c., which are to hang completely clear, it will be necessary to attach copper wire of sufficient length to the plain surface of the work, which must be bent to the particular shape, and placed in positions that will not interfere with the design of the work when viewed from the floor.

The manner of giving the embellishments a boldness proportionate to the height of the rooms in which they are executed, can be attained by practice and shrewd observation alone; but a knowledge of drawing, and a facility in sketching, will be found of great assistance in the acquirement of this department of ornamental plastering.

Enriched mouldings in cornices, prior to the invention of cast-work, were also worked in their situations by filling the spaces left for them with soft stucco, on which was pressed a reverse leaden mould, which left the impression of the ornament, this impression being afterwards *cleaned up* with steel tools.

The method of stucco-working practised at the present day, and which is commonly applied to Gothic work, is also first *roughed out* with gauged fine stuff, and followed up by a coat of stucco, composed of putty and fine sand, which also must be gauged. The ornaments being first worked into their proper shape, must be *cleaned off* with small steel instruments called scratch-tools, which being on their edges similar to a fine saw, leave on the work a matted surface which greatly adds to its effect at a proper distance.

Modelling.

368. The whole of the ornaments cast in plaster of Paris are previously modelled in clay, which method, as we have before stated, has of late years almost entirely supplanted the process of working the ornaments in their places by hand.

Having, in our explanation of the different styles of ornament, pointed out to the young artist what we conceive the best examples to study from in forming a correct taste for modelling, it will be quite unnecessary to revert to the subject again in this place.

Large works, such as angle-pieces, and foliage for ceilings, require more judgment than enriched mouldings, such as ogees or ovolos, as the eye of the modeller in the former case being his sole guide, whereas, in the mouldings, the compasses are found of essential service.

For example.—In the modelling of an ogee similar to *fig.* 3, in our Greek plate, No. 1, only one of the divisions is requisite to be modelled in clay, which may be effected by procuring a templet exactly corresponding with the profile of the moulding, and running a small portion of the moulding out with it in clay, in a small case of wood adapted to the purpose. The design of the ornament is then marked on the clay, and modified to its peculiar form by the use of tools made of ebony and box, and finally polished with brass tools. When finished in the modelling, it is moulded in wax, and a sufficient number cast and fixed together to a length varying from eight inches to one foot, and afterwards cleaned up and corrected with steel and brass tools. This piece of ornament, after being properly corrected, is called an original, as an unlimited number of moulds may be taken from it.

In modelling an angle-piece, similiar to *fig.* 5 in our French plate, it is necessary to run out a sufficient quantity of the plain moulding in putty and plaster to the exact form of the angle. The embellishments are then modelled on the mouldings, and also moulded thereon, the mouldings forming a ground for the ornaments, so that, after being cast, they will exactly fit the mouldings when fixed in their proper situations on the ceilings.

In modelling friezes, a ground of clay must be floated out to the length and width required, on which the design must be marked and finished in the usual way.

Moulding Ornaments.

369. There are two methods of moulding practised by plasterers, viz. moulding in wax, and moulding in plaster. The former is applied to all kinds of cornice enrichments, as friezes, soffits, ogees, ovolos, &c., and also to centre flowers and angle pieces. The latter is generally employed for works of large dimensions, which, from the manner in which they are *under-cut*, are not easily cast in wax moulds, as coats of arms, trophies, and plain capitals attached to trusses; it may also be applied to works in Roman cement, such as balustrades, heads, &c.

In moulding in wax, the clay model must in the first place be well oiled with sweet oil, and a fence of clay put round it to prevent the liquid wax from escaping, after which a sufficient quantity of wax and rosin must be dissolved together, which, when lukewarm, must be poured over the model until it is completely covered. When the wax is sufficiently set, the whole must be immersed in water, which will cause the wax *to leave* more readily, after which the clay being all washed out of the mould, it will be fit for casting in. This method will be found sufficient where a face-mould only is required, but when what is termed a *back and front* is wanted, as is the case in all leaves for centre flowers, it is requisite to cut the front plaster-cast back, so that the raffling shews distinct, and afterwards to soak it in water. The leaf must then be backed up all round within one-sixteenth of an inch of the edge with a substance of clay an inch wide, in which rivets must be inserted. The leaf being freed from all particles of water which may

remain on the surface, the clay must be well oiled. A fence of clay is then put round the whole, and the wax poured on, which, after remaining until quite hard, must be turned upside down, and the clay all removed from it, when the wax must be oiled, or the whole brushed over with a little liquid clay. Another quantity of wax must be prepared, and, when almost cold, poured over the first, which will form the back mould; a fence of clay being previously put round to prevent the wax from escaping. When this mass is sufficiently set, the two parts may be disunited, and the plaster-leaf removed, thus forming two moulds, the one for casting the back, and the other the front of the leaf. This manner of moulding is also used for all kinds of foliage, which needs much relief.

Moulding in Plaster.

370. In moulding in plaster, the same as in wax, the clay-model must be oiled with sweet oil, but the plaster must be laid on (not too soft) by one piece at a time, forming the joints, and fitting them to each other in such situations as the skill of the workman may suggest. After having completely covered the model with pieces, the whole must be removed, and when perfectly dry, soaked in boiled linseed-oil. The various parts of the mould being well saturated with oil, and quite dry, are fit for use, and may be oiled, ready for casting, with sweet-oil, in the same manner as wax-moulds.

Casting in Plaster.

371. The moulds being prepared and properly cleansed, are oiled in the way above-mentioned. A sufficient quantity of plaster of Paris, being mixed with water to a semi-fluid state, is well *dubbed* into the mould with a small brush, which, after remaining a short time, is floated off flush with the rim of the mould. The plaster being set, the impression is taken from the mould by means of pressing the wax gently with the hands all round, the heat of the plaster causing the mould to yield. The ornaments, after being taken from the mould, are cleaned up and cut with the trimming-knife to the proper joints, ready for the workmen to fix in the places intended for their reception.

Friezes and basso-relievos should always be cast with a half-inch ground at their backs, which serves to strengthen and secure their proportions.

Fixing Ornaments.

372. When the enrichments about to be fixed are small in size, they may be fixed in the grooves or indents prepared for them, with putty well gauged with plaster; but when the ornaments are of a weighty description, it becomes necessary to use fine stuff, and to cut away the plain surface of the work as far as the lathing. The place, so cut away, is then filled with

gauged fine stuff, and the cast being well scratched on the back in the form of a dove-tail, must also have a portion of fine stuff laid on it when it is placed in its proper position, and pressed to the work, so that they may both incorporate.

When the ornaments are extremely heavy, such as coats of arms and shields, in addition to the above mode, it is indispensably necessary to have recourse to large screws, which must pass through the cast-work into the timbers.

CHAPTER V.

DESCRIPTION OF THE PLATES OF ORNAMENT BELONGING TO PLASTERING.

373. *Plate* XL. Gothic Ornament.—*Fig.* 1, is an enrichment suitable for a hollow, taken from Ely Cathedral. *Figures* 2 and 3, are square flowers adapted for the filling of panels, which may be enlarged or diminished by the modeller, according to circumstances. *Fig.* 3, being from the remains of Sefton Church, near Liverpool. *Fig.* 4, a spaced ornament, after the manner of the celebrated Mr. Joseph Bernasconi. *Fig.* 5, is a spandril from Westminster Abbey, in which the portcullis is introduced. *Fig.* 6, represents another spandril taken from St. Catherine's Church (which was situated on Tower-hill) before its demolition, which of course renders it more valuable. *Figures* 7 and 8, are bosses, from the Cathedral Church of York. *Fig.* 9, shews the peculiarities of the style in which the ornaments in York Cathedral are executed; and *fig.* 10, from Salisbury Cathedral, contrasted with it, exhibits, at one view, the great difference in the decoration of the two cathedrals.

Plate XLI. Gothic Ornament.—*Fig.* 1, a finial from Sefton Church, Lancashire. *Fig.* 2, is an oblong panel from the west front of Wells Cathedral. *Fig.* 3, an ornament from the screen, at York, joining the choir. *Fig.* 4, a pendant belonging to one of the canopies in the Chapter-house, York. *Fig.* 5, is a pinnacle from the north-east front of Salisbury Cathedral. *Fig.* 6, a grotesque head attached to one of the stalls in the Chapter-house, York. *Fig.* 7, a battlement from Ely Cathedral. *Fig.* 8, finial from Westminster Abbey. *Fig.* 9, a panel from Wells Cathedral. *Fig.* 10, is from a design by Mr. W. Brown.

374. *Plate* XLII. Elizabethian Ornament.—*Fig.* 1, represents a running ornament, from the seat of the Marquis of Bath, at Longleate, in Wiltshire. *Fig.* 2, is an oblong panel from the hall of the Middle Temple, London. *Fig.* 3, is from the back of the ebony chairs formerly at Hampton Court, but now placed in the magnificent corridor in Windsor Castle. *Figures* 4 and 5, are the pilasters of Ann of Cleve's monument in Westminster Abbey. *Fig.* 6, displays the front and profile of a bracket executed in the reign of Charles the First.

375. *Plate* XLIII. Roman Ornament.—*Fig.* 1, exhibits the entablature of the Temple of Jupiter Stator, the most beautiful example of the Corinthian order now extant. *Fig.* 2, shews

the soffit of the corona. *Fig.* 3, is a modillion of a peculiar shape, from the splendid example of the frontispiece of Nero, at Rome. *Fig.* 4, is an ovolo from Vignola. *Fig.* 5, ogee and dentils, from the same celebrated architect. *Fig.* 6, shews the exact form of the Roman bead.

376. *Plate* XLIV. French Ornament.—*Fig.* 1, represents an elaborate frieze running from a centre, which might be judiciously introduced into a cornice. *Fig.* 2, is an enriched cyma recta, with an appropriate bead attached to it. *Fig.* 3, shews the profile of a large bracket suitable for the reception of a bust or figure; it might also be adopted for the support of a moulding at the springing of an arch. *Fig.* 4, exemplifies the variety of this style when applied to the decoration of ceilings by a complete angle-piece, with the frame-moulding attached, and fully enriched with the shell and festoons of flowers. *Fig.* 5, is an enrichment applied to a hollow, or cavetto, which would produce a pretty effect in a small cornice.

CHAPTER VI.

377.—AN EXPLANATION OF THE TERMS, AND DESCRIPTION OF TOOLS, USED IN PLASTERING.

Alabaster; plaster of Paris in its unprepared state.

Antique Ornaments, are those which were employed by the Greeks and Romans. Antique architectural ornaments, such as capitals and friezes, are at the present day held in high estimation, as they serve as examples to copy from in the embellishing of edifices in the Greek or Roman style of architecture.

Bass-Relief, or Basso-Relievo; a model, or cast, in which the figures do not project from the ground, with their full proportion. M. Felibien enumerates three kinds of basso-relievos; in the first, the front figures appear almost with their full projection or relief; in the second, they stand but one-half; and in the third, much less, as in coins and vases.

Beaters, are used for making the coarse stuff fit for laying on. There are two forms of beaters; one being similar in shape to a common shovel, and nearly the same size at the lower end, and made out of a piece of deal one inch and a half thick, tapered up towards the handle so that it may be conveniently used. The other is formed from a piece of wood about five feet in length, and one inch and a half thick, leaving the end which comes in contact with the mortar in the process of beating the necessary size; rounding and thinning it down towards the end which is held by the labourer.

Binn; a sort of dam of any convenient size, formed with bricks, and made perfectly water-tight, for the purpose of containing putty, stucco, &c.

Blister; a protuberance on the surface of plastering, caused by the bursting of a small portion of the lime.

Boasting Tool; that which is used for giving the primitive form to ornaments which are worked by hand.

Boss; a Gothic ornament, which covers the intersections of the mouldings on a groined ceiling.

Cast; any form produced from a mould; but, in plastering, more particularly applied to ornaments composed of plaster of Paris or Roman cement, produced from wax, plaster, or sulphur moulds; ornaments formed in this way being entirely distinct from those made in terra cotta, or mastic, which are pressed.

Coat; a stratum or thickness of plastering done at one time.

Corbel; a Gothic termination of one or more groins. Corbels are, in some cases, composed of mouldings alone, and in others, enriched with leafage, heads, &c. An example of one filled with leafage may be seen by referring to *plate* XLI. *fig.* 10.

Core, or Bell; the ground-work on which the volutes and leaves of a Corinthian capital are placed.

Crocket; an ornament which creeps up the pinnacles in Gothic architecture, an example of which is furnished in *plate* XLI. *fig.* 5.

Cylinder, in plastering, is technically applied to the apparatus used in forming the portions of mouldings for a Gothic intersection, which terminates on a corbel or capital.

Derby; a two-handed float, composed of a piece of wood, three feet six inches long, four inches and a half wide, and three-quarters of an inch thick.

Dots; the guides for the floating-rule to work on in forming a screed.

Drag; a three-pronged rake, used in incorporating the hair and sand with the lime in preparing coarse stuff.

Egg-Mould; the ovolo enriched in a peculiar manner, somewhat resembling an egg encircled by bands.

Emboss; the projection of ornaments from their ground.

Fine Stuff; the kind of stuff used for giving the finishing coat to the work.

Finial; the ornament which forms the extreme termination of a Gothic pinnacle, examples of which may be seen in *plate* XLI. *figures* 1 and 8.

Floating Rules, are composed of a piece of deal about an inch and a half thick, and are used for bringing coarse stuff to a straight surface, and also for forming screeds.

Frieze, in architecture, is the portion between the architrave and the cornice in an entablature; in plastering, it has seldom more than a small moulding under it.

Gauging-Trowels, are used in the laying on stuff for mouldings, &c., and are generally made of a thin piece of plate-steel, about eight inches long, and two inches and a half wide, at the handle-end, and tapered off to a point at the other. A smaller one is also sometimes used, about six inches long, and of a proportionate width. The handles of these trowels are made of wood.

Hand-float, is composed of a piece of wood, 10 inches long, four inches and a half wide, and five-eighths of an inch thick, with a handle of the same material attached to it, and is used in finishing trowelled and rough stucco.

Hawke, is used by the plasterer for the purpose of holding stuff on, and is generally made of a piece of deal, 11 inches square, and three-quarters of an inch thick, thinned off to the edge, with a handle four inches long affixed to the under side, for the purpose of holding it.

Honeysuckle; an ornament from nature, first introduced into architecture by the Greeks. See page 173.

Lop-sided; a piece of ornament is said to be lop-sided, when both the sides which spring from a centre, do not correspond with each other.

Lotus, or Water-Lily; an aquatic plant, the representation of which was first used in decoration by the Egyptians.

Model, in plastering, signifies a piece of ornament finished in clay; it is also applied to a building in miniature, executed in plaster.

Pan. See *Binn.*

Patted and Pressed Work; a method of working in stucco, invented by Vittoria, a pupil of Giocomo Tatti. See page 172.

Planceer. See *Soffit.*

Pricking-up; the first coat. See page 189.

Raffling; the notched edges of foliage.

Rose; the term rose is applied to the ornament which is inserted in the coffer of the Corinthian soffit.—Rose also signifies any plaster-ornament which bears any resemblance to the rose of nature.

Scratch-Tools, are made of pieces of steel, varying from 9 to 11 inches in length, flattened out towards the ends, which are notched in a similar manner to a fine saw, and are used for the cleaning up of ornaments.

Screed, in plastering, signifies a border about eight inches wide, formed on a ceiling or wall, for the purpose of running a moulding on.

Setting; the quality that any composition possesses of getting hard in a short time. This term is also used for a thin coat of putty. See page 190.

Sieves, are of various degree of fineness, being used for the purpose of straining liquid-lime through in the preparation of putty, &c.

Soffit, from the Italian word *Soffito*, means the under part of the corona, and is also applied to the under parts of the heads of doors and windows.

Spaced Ornaments; are those fixed in Gothic cornices, with a plain space between them.

Spandrils; spaces, either plain or ornamented, between an arch and the square formed round it.

Templet, in modelling, a thin piece of wood, in which is cut the profile of an enrichment, for the purpose of running it out in clay previously to its being modelled.

Trimming-Knives, are from three to five inches in length, tapered off to a sharp point; they are used for cutting or trimming ornaments.

Tripoli; called also alana; a kind of chalk or soft stone of a yellowish grey colour, used in polishing of scagliola.

Truss; an ornamental support.

BOOK IV.

SLATING.

378. SLATE, a laminated species of stone, which is generally of a bluish colour, and which may be split into parts, or slices, so very exactly, that their substances will be very nearly comprised each between two parallel planes.

Slate is extracted from the quarries in the same manner as other stony substances. The strength of slate to that of Portland stone has been computed to be in the ratio of five to one. The thickness of slates is very variable; fine slate is so very thin, that six of them may be comprised within an inch, which will be the average thickness of only three of the coarser kind The average thickness of slates, in general, will scarcely exceed a quarter of an inch.

Slates, used in the covering of buildings, vary in their dimensions, from one to three feet in length, and from six to twenty-four inches in breadth. Their thinness renders them extremely light; and since they are, at the same time, both strong and durable, they are well adapted to the covering of buildings. Wales and Westmoreland are the sources from which our slate is generally procured. The Welsh slates are generally considered as the best, and are, in colour, approaching to sky blue. The Westmoreland incline to the colour of a dull light green.

379. Slates may be so arranged upon the surface of a timber boarding, as to prevent the drifting of snow or rain by the most heavy winds; but to prevent this, it is necessary to lay them in courses, or rows, to incline the plane surface of the boarding to the horizon at a sufficient angle, to make the joints between any two slates of every course as close as they can be conveniently made, and to make them fall each upon the central line of a slate in the course below them. By this means, the roof may be rendered comfortable and secure from the penetration of moisture or wet.

It is evident, that close joints between every two slates, and an equality of length throughout every course, will greatly contribute to the perfection of the work, as well as to its regularity. To make close joints between every two slates which join, two edges of every slate must be made straight and parallel to each other; and to preserve regularity and beauty in the work, the edge intended to be the lowest part of the slate must also be made straight and perpendicular to the other two, in order that the lower extremities of every course may be arranged in a straight line.

Such a covering, however, as slate, being subjected to the force of heavy winds, could never be permanent without some ligature to connect the slates with the boarding, they are, therefore, generally secured by means of one or more iron nails driven through their thickness into the boarding. For the purpose of letting them pass freely, the slater makes one or

more holes through each slate, sufficient to admit the thickest part of the shank of a nail, but not the head.

Small fine slates have generally their edges straight, and at right-angles to each other. We have already mentioned that, for the security and regularity, as well as for the beauty of the work, it is necessary that every slate have three straight edges, the bottom end being at right-angles to the other two, the upper end of the slate is therefore either straight or rough; but when it is rough, a small portion in the middle of the breadth ought to be straight, and no part ought to be indented, but rather convex.

When very small slates are employed, one nail to fasten each of them will be sufficient; therefore, in every course of such slates throughout, the holes ought to be at an equal distance from the lower edge of the course, for reasons which will afterwards make this evident, and each hole should be as near to the middle of the breadth of the slate as it can be conveniently made; but when large slates are employed, two holes will, at least, be found necessary; and, in order to place them to the best advantage, they ought to be as close to the edges which are intended to join, as is consistent with the strength of the slate, and situated in the part of the surface intended to be concealed; but here it is not absolutely necessary, with a boarding underneath, that these holes should be at an equal distance from the lower end of the slate, as the shape of the slate often requires them in various positions; however, regularity in this respect will also contribute to the strength of the work.

If, in every course of large slate, the nail-holes were all equi-distant from the lower edge of each slate, and if the courses succeed each other in equal breadths, or in their succession towards the top of the covering by a regular diminution, all the nail-holes of any and every course of slating would be in a straight line, and all the straight lines would be parallel to each other; therefore, the timber used for the immediate fastening of the slates would only be required to extend along these lines, and to be of sufficient breadth and thickness to support the courses, and to resist splitting when the nails are driven home to their places This circumstance has given occasion to the introduction of narrow pieces of timber, called battens, with large intervals between them, to be used instead of boards set closely together.

380. The two parallel surfaces of every slate are called its *faces*, and the narrow surfaces comprised between these faces are called the *edges*; the end of the slate, which is perpendicular to the other two, is called the *tail* of the slate; the face of the slate, which is intended to be the upper one, is called the *back*. The shortest dimension of slates, in the first courses, to a certain distance, is always placed in the work between the joints. As slates vary in all gradations of length, after having prepared three edges of each, they are then cut to the different lengths, and placed in heaps of various sizes, in regular gradations; but those which belong to any one of these heaps are all of an equal length. The different sizes are called gauges. The best face of every slate ought to be that which is intended for the back.

In every course of slating, the straight line formed by the lower end of the slates, is called the apparent edge of the course. The continued surface formed by the backs of the slates is

called the *back* of the course; moreover, the part of the back of every course which is exposed to the eye is called the *margin* of that course.

From what has been said, it is evident that a slated covering, constructed according to the foregoing principles, will exhibit, alternately, external and internal angles, having the arrises of the external angles parallel to one another, as well as those of the internal angles; that the external angles are formed by the margin and tail of each slate, and that the internal angles are formed by the margin of one course and the tails of the slates in the course immediately above.

381. We shall now endeavour to ascertain how much the slates ought to be lapped upon one another, in order that the covering may be secure from rain or snow. Suppose that the slates in a roof were all of equal length, and so laid that every slate in an upper course would just cover half the length of the backs of the slates in the next lower course; then, in every three adjacent courses of slating, a wire, or right-line, perpendicular to the plane of the margin of the middle course, and in the upper extremity of the joint between two slates, will fall upon the upper edge of the course below, and upon the lower edge of the course above; and, consequently, if the slates cover each other less than half their length, there will be an aperture at the upper end of every joint between two adjacent slates. It is therefore necessary, in order to close every opening, that one course may cover the adjacent lower course more than half the length of the slate.

In every three adjacent courses of slate, laid according to the principles here pointed out, if the nails are placed in the edges of the slates, the distance between the top of the slate of the lowermost course, and the lower end of the slates in the uppermost course, is called the *bond* of the covering; or, if the slates have a nail in the middle of the head of each, the distance which that nail in the lowermost course is above the lower ends of the uppermost course in the sloping or inclined direction of the boarding, is called the *bond* or *lap* of that course. Opposite to the bond of every course, the slates are in three thicknesses, but in all other places they are in two thicknesses only.

When the courses are all of equal breadth, the part which is covered of every course is equal to the half sum of the length of a slate and the breadth of the bond, the breadth of the margin or visible part of a course is equal to half the difference between the length of a slate and the breadth of the bond. Moreover, the breadth of those parts in which the slates are in two thicknesses, is equal to the difference between the length of a slate and three times the breadth of the bond.*

* In order to make it convenient for computation, it will be useful to express these rules in formula. For this purpose, let l represent the length of a slate, and b the breadth of the bond; then will,

$\frac{l+b}{2}$ = the breadth of the part which is lapped or covered of a course;

$\frac{l-b}{2}$ = the breadth of the margin or visible part of a course;

$\frac{l-3b}{2}$ = breadth of those parts which are in two thicknesses

It is, however, more convenient in the practice of slating, and equally agreeable to the eye, to make the courses decrease in breadth in a regular progression upwards; therefore, when the breadth of the bond is one-third of the length of the slate, the breadth of those parts in which the slates are only two plus in thickness is nothing, or, in other words, the slates in this case are every where in three thicknesses, except in one point only. There are some architects who observe, as a general rule, to make the bond equal to one-third of the length of the slate; but, in the two extreme cases, this rule would give the breadth of the bond in the one extreme too little, and in the other too much; therefore, in the one extreme, the covering would not be secure, and in the other, there would be a vast waste of material. This rule is therefore false in principle, and will be more evident when we come to consider the different inclinations which arise from different elevations of roofs; it is therefore justly condemned by all experienced workmen.

In fastening the slates, it is of great importance to have the nails of a proper material, or to have them prepared in order to resist decomposition, as iron nails, in their natural state, would speedily decay. To prevent this, it will be proper to use copper or zinc nails; but as the expense of these is considerable, iron nails, plated with tin, have been lately introduced. Another expedient, in the use of iron nails, is to immerse them in a vessel of white-lead well saturated with oil, or indeed with linseed-oil only, and let them soak till the paint or oil completely adhere to their surface, they are then taken out, and when thoroughly dried, are fit for use.

It is the business of the slater to regulate and fix the boarding agreeable to the several gauges of the courses, and agreeable to the proper bond of the slating; and here, in order to save material, it will be useful to observe, that the boards may have open spaces between their edges; battens now, therefore, are more generally employed. It is a rule with slaters to use smaller battens when small slates are used, and larger battens when larger slates are used; thus, for instance, in the use of small slates, battens two inches and a half in breadth, and three-quarters of an inch thick, are generally employed, and in the use of large slates, battens three inches in width, and one inch in thickness, are employed; this will, however, depend upon the weight of the slates. By employing battens, instead of boards, an expence of twenty shillings in the square will be saved, speaking in a general way; because, in some cases, the breadth of battens are not more than one-fifth part of the breadth of boards, and hence the adoption of boards will necessarily be attended with an enormous waste of timber.

Regularity in the breadth of the courses is of the greatest importance; if the slates are not of equal lengths, they ought to diminish in a regular progression, and at the same time the slater should be careful to select them of such thickness, as to be proportional to the breadth of the margins of the courses which they are in. The thickest slates should therefore be those in the lowest or first course, and the thinnest those in the highest course.

Unless that these gradations and proportions are attended to in the execution of the work, the slates can never be made to lie upon boards or battens arranged in a plane surface; or otherwise, if the tops of the slates are brought close to the boarding or battening, the beds cannot be made to coincide; in such a case, the greatest bond would not be able to prevent the penetration of winds, nor the drifting of rain or snow, and, in the act of repairing the roof, the slates, from their surfaces only partially coinciding, and generally open, would be liable to break in being trod upon.

If all the courses of slates were of one and the same thickness, the surface of the boarding would require to be curved with a small incurvation at the bottom of the roof; but continually increasing towards the top, where it is the greatest, provided the slate have a continual diminution, for if the breadths of the slates are equal, the line which their edges preserve will be a straight line. Moreover, if the slates were to diminish in the breadth of the courses, as they succeed each other, without diminishing in thickness, the weight of the same quantity of surface nearer to the top of the covering would be greater than that nearer to the bottom, and this inequality would occasion a very considerable waste of materials, and an unnecessary burden on the timbers of the roof.

Another observation, which is of no less importance, is, that care should be taken, in selecting the slates, to make them all of one breadth throughout the covering; that is, the distance measured in a horizontal direction between every two adjacent joints should be the same every where. Any irregularity in this respect would weaken the bond, and would greatly contribute to lessen the good effect of the regular gradations of the margins. Nothing short of the whole combination of these circumstances, and the choice of slates of the best quality, will make a comfortable and secure covering from inclement weather. Though a small deviation may be occasionally admitted, in order to accommodate certain sizes of slate, and though this may be of little consequence, every departure from these regulations will deteriorate from the quality of the work.

382. The ratio which exists between the distance which a roof stretches from wall to wall, and the height of the roof, is called the pitch of that roof, and thus the pitch of a roof may be determined also by the angle which the sloping sides make with a plane parallel to the horizon. The most approved pitch of a roof, which is also very agreeable, may be comprised between the angles which are formed by making the height of the roof one-fourth and one-third of the breadth of the building. In these extremes, one-third is the ratio of 3 to 1, and one-fourth the ratio of 4 to 1; but we shall here recommend a pitch half-way between these, namely, that of a right-angled triangle, which is the half of an equilateral triangle; therefore the angle at the base will be 30°, and half the vertical angle of the roof will be 60°. The angles at the bases of the three roofs will be as follow:—

When the height of the roof is one-fourth of the breadth of the building, its inclination is ..... 26° 24′

When the length of the rafter is the side of an equilateral triangle, and the base the perpendicular, its inclination is ---------- 30° 0′

When the height of the roof is one-third of the breadth of the building, its inclination is ---------- 33 41

The roof in which the angles at the base are 30°, is very convenient in the mensuration of slater's-work, since we require no effort to get at the breadth of the sloping sides; for then the breadth of both sides, or twice the length of the rafter, will be equal to four times the height of the roof.

Agreeably to these extremes, it has been found, by long experience, that the breadth of a suitable bond for the slates ought to be from about two and a half to three inches, observing, however, that, in either case, the slates thus employed ought to be of the best quality, and of the largest size. The bond of the slates, in order to make a water-tight roof, depends not only upon the pitch of the roof, but upon the length and thickness of the slates. As a roof requires to be repaired, the slates ought to be of such thickness as to be sufficient to resist fracture in being trod upon. A low pitched roof will require the slates to have more bond than one that is higher.

If the lengths of the slates which form the breadths of the courses in their consecutive order are given, whether in arithmetical progression, or in any irregular numbers, it is plain, from the nature of the bond depending always upon the third course, that the position of the slates in the first, third, fifth, seventh, &c. odd courses are altogether independent of the slates which constitute the series of the even courses. Upon this consideration, the practice of laying the slates of a roof depend upon the following principles:—

1st. The difference between the length of a slate in any course, and the breadth of the bond, is equal to the sum of the margin of that course and the margin of the course next above.

2d. The difference of the lengths of the slates in two adjacent courses is equal to the difference of the margins of the slates in the lower course, and the slates in the course next above these two courses.

These principles will be true, whether the slates in the courses as they rise are in a regular or irregular order; but, if the slates of the courses follow in equal length, or in any decreasing arithmetical progression, as they usually do, we shall, by means of these two principles, arrive at the sum and difference of two margins in any two consecutive courses, and thus determine the breadths of these margins, and, consequently, the breadths of the whole series of margins from the eave to the ridge.

In the case in which the length of the slates of the consecutive courses form a decreasing arithmetical progression, the difference between any two adjacent margins is equal to half the difference between the lengths of the slates in any two adjacent courses.

Example.—Let there be given the following decreasing arithmetical series, expressing the lengths of the slates in inches, of the consecutive courses, and let the breadth of the bond be

three inches, to find the breadth of the margins, the distances of the battens, and the breadth which any number of slates will cover,

30, 28, 26, 24, 22, 20, 18.

Now, because the difference of the slates in two adjacent courses is two inches, the difference between every two adjacent margins is one inch, and because the difference between the length of the first slate (30 inches) and the breadth of the bond (3 inches) is 27 inches, we have the sum 27 of the margins of the first and second courses, and their difference, to find the margins themselves; whence we have $\frac{1}{2}(27+1)=14$ the lower margin, and $\frac{1}{2}(27-1)=13$ the upper margin; hence the progression of the margins is the series—

14, 13, 12, 11, 10, 9, 8, 7, 6, &c.

The sum of as many terms of this series will be the breadth which as many courses will cover; suppose nine terms are summed, we have by the common method $\frac{9\,(14+6)}{2}=90$ inches, or 7 feet 6 inches. By adding the breadth of the bond to 14 inches, the first term, makes 17 inches, which is the distance from the lower edge of the eave to the upper edge of the first batten, and 13, 12, 11, &c., are the respective distances of the upper edges of the battens as they ascend.

It will not be more difficult to compute the necessary distances when the slates are ranged in any promiscuous order of the courses, observing, however, that the alternate odd courses, viz. the first, third, fifth, &c., not only fixes the number of courses and the position of the slates in these courses, but the breadth which they will cover. As to the even courses, the breadth of the margin of the first course fixes the position and distances to which any number of them will extend.

Example.—Having given the lengths, 36, 29, 35, 39, 30, 25, 18, &c., of the slates, in inches, of the consecutive courses of a slated covering, the breadth of the bond three inches, and the breadth of the first margin 17 inches, to find the breadths which any number of courses will cover, the margins of the slates, and the distances of the battens.

By subtracting three inches from the lengths of the slates in the odd places of the courses, we get the following lengths, viz. ..... 33, 32, 27, 15, &c.
and taking three inches from the lengths of the slates in the even places
of the courses, we obtain ..... 17, 26, 36, 22, &c.
by placing 17 as the first term. Then, taking the successive sums of the first of these two series of lengths, and also the successive sums of the second, and place them so as to form the following two series:—

33, 65, 92, 107, &c.
17, 43, 79, 101, &c.

Then, arranging these two series into one, observing that the numbers rise higher in every succeeding term, and we shall have the following series of numbers:—

17, 33, 43, 65, 79, 92, 101, 107, &c.

which are the successive breadths which one, two, three, &c. margins will make. Hence

the eighth term, 107 of this series, is the breadth in inches of eight margins, equal to 8 feet 11 inches.

Again, by taking the differences of the terms of this last series, we obtain the following:— 17, 16, 10, 22, 14, 13, 9, 6, &c., which are the breadths of the margins as far as the series is carried, viz. of eight margins. Moreover, cutting off the first term of this last series, the remaining terms, viz. 16, 10, 22, 14, 13, 9, 6, &c., are the respective distances which the upper edges of the battens are from each other, and if to the first term, 17 inches, we add 3 inches, the sum 20 is the distance of the upper edge of the first batten from the lower edge of the eave.

383. — EXPLANATION OF THE PLATE ILLUSTRATING THE PRINCIPLES AND PRACTICE OF SLATING.

Plate XLV. No. 1, 2, 3, 4, 5, 6, exhibits the various proportions of Welsh slates from rags, or Queen's to doubles. No. 7, a fine slate; these are generally squared all round, have their surfaces very smooth, and of a substance so thin that six of them may be comprised in an inch.

Fig. 1, exhibits a portion of the section of the side of a slated roof, the length of the slates being 30 inches in the breadth of the upper course of the eave, and diminishing gradually by a common difference of two inches in each succeeding course, as in Example 1, (see the scale below,) and thus making the breadth of the margins in arithmetical progression, having a common difference of one inch. The first margin is 14 inches, therefore the second 13, which is the distance between the heads of the slates, which form the eave. In this section, the thickness of the slates is proportioned to the distance between the heads, the slates are therefore thickest at the bottom, and continually thinner the nearer they approach to the top, which are therefore of the least thickness.

In *figures* 2, 3, 4, which are also sections of the covering of a slated roof, the lengths of the slates as they succeed each other, and the breadths of the margins, are the same as in *fig.* 1; but their thickness is about four times the thickness of the slates in *fig.* 1, in order to explain the principles, and show the proportions to more advantage.

The section, *fig.* 2, shows the diminution in the thickness of the slates more sensibly than the section, *fig.* 1. Let (in *fig.* 2,) *c d*, *e f*, *g h*, &c., be the respective distances between the heads of the slates; these distances, expressed in inches, will be 13, 12, 11, &c. inches, which are the same as the breadths, CD, EF, GH, &c. of the margins, but not the same as the distances, *b d*, *d f*, *f h*, &c. of the upper edges of the battens, being a trifle more than the distances between the heads of the slates. The distances between the battens being, however, made the same as those between the heads of the slates, will not occasion any sensible error, neither in the breadths of the margins nor in the distances between the heads of the slates, and, consequently, will neither affect the practical operation nor yet the result arising from it.

For the distances between the battens are the hypothenuses of right-angled triangles, of which the distances between the heads of the slates may be considered as the bases, and the thickness of the slates the perpendiculars; but, as these thicknesses are so very small, the bases of the triangles will be so very nearly equal to the hypothenuses, that the differences cannot be made sensible to the eye. For example, suppose the thickness of the slate to be half an inch, and the distance between the two first battens 13 inches, as in *figure* 2. Suppose that these distances are doubled, then the results will be doubled, the double of $\frac{1}{2}$ and 13 are respectively 1 and 26, which are the perpendicular and base of the triangle; now, to find the hypothenuse we have $1^2 + 26^2 = 1 + 676 = 677$, of which the square root lies between 26·01 and 26·02; hence the hypothenuse is less than 26·01 inches; hence the difference between the base and hypothenuse of such a triangle is less than ·01, or less than the hundredth part of an inch, which could scarcely be rendered visible to the eye, and the error in laying a covering of slates to one hundred times this breadth, which is 108 feet, would not amount to an inch, therefore, in covering the largest roofs, this error could scarcely ever exceed a quarter of an inch upon any inclined face of a roof.

But, although there is no practical differences between the distances of the heads of the slates and those of the battens, the thicknesses of the slates will give them an elevation above the battening proportional to their thickness. Thus, in the ratio of 1 to 26, the angle which the planes of the slates make with the plane of the battening will be 2° 12′, and if the slates be three-eighths of an inch thick, the angle which the plane of the slates make with the plane of the boarding will be 1° 33′.

To find this angle by a practical method. Let CD, *fig.* 6, be equal to *c d*, *fig.* 2. In *fig.* 7, draw CB perpendicular to CD, and make CB equal to the thickness of the slate. Join BD, and the angle CDB is that which the faces of the slates make with the plane of the boarding. In *fig.* 2, having drawn *d c*, by making the angle *b d c* equal to the angle BDC, *fig.* 7, prolong *d c* to *r*, and through the remaining points, *f*, *h*, *j*, *l*, &c., draw the straight lines *h* D, *j* F, *l* H, &c., and the distances between these lines are the thicknesses of the slates which evidently diminish in proportion to the distances between the heads of the slates.

Fig. 3, exhibits the same breadths of slating, as in *figures* 1 and 2; but in this section the thickness of the slates being all equal, causes them to recede farther from the boarding, as they are more distant from the eave, and thus, instead of following the straight line of the section of the boarding, they assume a line of a curvilineal form; but, if the heads of the slates were brought to their proper places upon the battening in the straight line, the slates above the eave course would open gradually, as in *fig.* 4, so that their under-surfaces would only lie upon the edges of the heads of the slates below them. Such positions would render the covering insecure, not only in the slates being liable to be broken by heavy winds, and by being trod upon in repairing the roof, but, by their being open, in admitting the rain, snow, or inclement weather, to penetrate without resistance.

The section, *fig.* 5, is given as an illustration of the second example, in which the slates, though equal in length throughout each course, follow one another in the succeeding courses of such irregular lengths which, when measured by the scale, will be found to succeed each other in the different courses, the same as those in the second example. Here, besides the irregularity in the breadths of the courses, in order that the slates may lie upon a straight or plane surface, the thicknesses of the slates must also succeed each other in the same irregular manner. The disagreeable effect of these incongruous proportions will be evident on inspecting *fig.* 5, here alluded to. This example is useful, as it not only illustrates the general principles of slating, but how to avoid the disagreeable appearance of such an arrangement, and the unnecessary load of material.

Fig. 7, exhibits the three pitches of roofs, already alluded to, for slated coverings, best adapted to the climate of Great Britain. The lowest is that which is most frequently used in, or the vicinity of, London, and in the southern counties of England, the height, *ce*, being one-fourth of the span, AB, of the roof; the highest, on which the height, *cd*, is one-third of the span, is well adapted to the climate of Scotland; and the middle one, in which the height, *cf*, is one-half of the length, *f*A or *f*B, of the rafter, is adapted to the intermediate counties, and indeed, with proper care in the execution of the work, generally throughout Great Britain and Ireland.

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384. The slates most in use about London are the Welsh and Westmoreland, but the latter are now almost superseded by the former. About eighty years ago French slates were much used: they are smaller than Welsh slates, and, being very thin, are consequently extremely light; and their thinness renders them liable to be easily penetrated by wet, and are, of course, considered unfit for our climate. Slates of this kind, after they have been long exposed to the atmosphere in these countries, are often shivered in pieces; and they may sometimes be found completely decomposed, or reduced to a powdered state. This imperfection, since it has been known, has prevented their being used in this country; nor is it probable they will be again introduced.

The Welsh Slates are generally classed in the following order:—

	ft.	*in.*		*ft.*	*in.*
Doubles, average size	1	1	by	0	6
Ladies	1	3	—	0	8
Countesses	1	8	—	0	10
Duchesses	2	0	—	1	0
Welsh Rags	3	0	—	2	0
Queens	3	0	—	2	0
Imperials	2	6	—	2	0
Patent Slate	2	6	—	2	0

The DOUBLES are so called from their small size. These are made from the fragments of the larger qualities, as they are sorted, respectively.

The LADIES are made up from fragments, as above, in pieces that will square up to the size of such a description of slate.

COUNTESSES are in size the next gradation above *ladies;* and DUCHESSES still larger.

385. The IMPERIAL SLATING, for roofs, is particularly neat, and is known by having its lower edge sawn; whereas all the other slates, used for covering, are only chipped square on their edges.

386. PATENT SLATING is so called, among the slaters, from the peculiar mode of laying it on roofs, but we are not aware of any patent for it being ever obtained. It was first brought into notice by the late James Wyatt, Esq. the architect of our late revered king, George the Third. Patent slating may be laid on rafters of much less elevation than any other kind of slating; it is considerably lighter; because the breadths of the laps are much less than the slates adopted for the common sort of slating. Patent slating was originally composed of slates called the *Welsh Rags*, but at the present time it is composed of the *Imperials*, which are lighter, and much neater in appearance. Neither battens nor boarding is required for these slates; but the common rafters should be left loose on the purlins, so that a rafter may be fixed under each of the meeting-joints of the rows of slates. The work of covering is then performed, as already described, except that no bond is required, the slates being laid uniformly, and screwed down by two or three strong one-and-a-half inch screws at each end into the rafters beneath.

Filleting is now commenced, which consists in covering the meeting-joints with fillets of slates, bedded in putty, and screwing them down through the whole into the rafters. These fillets are then neatly pointed up with more putty, and then painted, to resemble the slates. The hips and ridges of roofs are sometimes filleted, but lead is preferable. The Patent Slating may thus be laid, perfectly water-tight, with a rise of two inches in one foot of a rafter.

These are the general modes of laying slates; and for peculiar neatness they are sometimes laid in a lozenge form, but as, in this form, only one nail can be used to each slate, thus laid they soon become dilapidated.

387. On the WESTMORELAND SLATE, some experiments were made by Dr. Watson, the late Bishop of Llandaff, whence it appears that there is very little difference in the natural composition of this kind of slate and that of Wales. The bishop's comparison of their absolute weight, as compared with the weight of other materials made use of as a covering to buildings, may be of great utility, inasmuch as it may tend towards forming a datum for adding to, or diminishing from, the quantity of timber employed in roofs of different spans and elevations. "That sort of slate," says his lordship, "other circumstances being the same, is esteemed the best, which imbibes the least water; for the imbibed water not only increases the weight of the covering, but, in frosty weather, being converted into ice, it swells and shivers the slate. This effect of the frost is very sensible in tiled houses, but it is scarcely felt in slated ones; for good

slate imbibes but little water; and, when tiles are well glazed they are rendered, in some measure, with respect to this point, similar to slate." He adds, "I took a piece of Westmoreland slate and a piece of common tile, and weighed each of them carefully; the surface of each was about thirty square inches; both the pieces were immersed in water for ten minutes, and then taken out and weighed as soon as they had ceased to drip, and it was found that the tile had imbibed about one-seventh part of its weight of water, and the slate had not imbibed a two-hundredth part of its weight. Indeed the wetting of the slate was merely superficial, while the tile, in some measure, became saturated with the water. I then placed both the wet pieces before the fire; in a quarter of an hour's time the slate was become quite dry, and of the same weight it had before it was put into the water; but the tile had lost only about twelve grains of the water it had imbibed, which was, as near as could be expected, the same quantity that had been spread on its surface; for it was this quantity only which had been imbibed by the slate, the surface of which was equal to that of the tile. The tile was left to dry in a room heated to 60° of Fahrenheit, and it did not lose all the water imbibed in less than six days." He adds, further, "that the finest sort of Westmoreland slate is sold at Kendal at 3*s.* 6*d.* per load, which will amount to 1*l.* 15*s.* per ton, the load weighing two hundred weight. The coarser sort may be had at 2*s.* 4*d.* a load, or 1*l.* 3*s.* 4*d.* per ton. Thirteen loads of the finest sort will cover forty-two square yards of roofing, and eighteen loads of the coarsest will cover the same quantity; so that there is half a ton less weight put upon forty-two square yards of roofs, when the finest sort of slate is used, than if it was covered with the coarsest kind, and the difference of expense only three shillings and sixpence." It must be remarked, that this slate owes its lightness, not so much to any diversity in the component parts of the stone from which it is split, as to the thinness to which the workmen reduce it, and it is not so well calculated to resist violent winds as that which is heavier.

COMPARISON IN WEIGHT OF THE SUNDRY COVERINGS EMPLOYED ON ROOFS.

388. A Common Plain Tile weighs thirty-seven ounces, and they are used, at a medium, seven hundred to cover a single square of roof of one hundred superficial feet.

A Pan-tile weighs seventy-six ounces, or four pounds and three-quarters, and one hundred and eighty are required to lay on a single square of roof.

Both the plain and pan tiles are commonly bedded in mortar; indeed the former cannot be well laid on a roof without it. The mortar used may be about one-fourth of the weight of the tiles.

Common Lead or Copper, for covering roofs, generally requires seven pounds of the former, and seven ounces of the latter, for each superficial foot. A square of one hundred feet covered with the above materials stand relatively thus:—

	cwt.	*qrs.*	*lbs.*
For Copper, per square	0	3	16
Lead	6	1	0
Fine Slate	6	0	21
Coarser ditto	8	1	8
Plain Tiles	18	0	0
Pan-Tiles	9	2	0

Hence a careful builder may select such a covering as his building may be best adapted to support.

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389. The SLATERS' TOOLS are the *Saixe, Ripper, Hammer, Shaving-Tool,* and various kinds of *Chisels, Gauges,* and *Files.*

The SAIXE is of steel, and not unlike a large knife, except having on its back a piece of iron, projecting about three inches, and drawn sharp to a point; it has a handle of beech, and is used for chipping and cutting slates.

The RIPPER is formed of iron, about the same length as the Saixe, with a very thin blade, tapering towards the top, where a round head projects about half an inch, with two little notches at the intersection of one with the other. This tool is used for lifting up and removing the nails out of old slating, when it is to be repaired.

The HAMMER differs but little from the common tool of the same name, except that the upper portion of the driving part is higher and bent towards the handle, so as to form a claw, by having a notch in its centre. It is used for extracting nails that do not drive satisfactorily.

The SHAVING TOOL consists of a blade of iron, about eleven inches long and two wide, sharpened at one of its ends, like a chisel, and mortised into two round wooden handles. It is used for smoothing the surface or face of a slate, for skirtings, floors of balconies, &c.

The CHISELS, GAUGES, and FILES, need no description. They are used for finishing the better parts of the slater's work, as mouldings, chimney-pieces, skirtings, casings, &c.

VALUATION OF SLATERS' WORK.

390. SLATERS' work is measured by surveyors by the square of 100 feet superficial. Besides the nett dimensions of their work, slaters are allowed six inches for eaves, and four for hips, for common slating; and nine inches in addition for rags or imperials. Slating for roofing may be averaged thus per square.

	£.	s.	d.
Doubles	2	2	0
Countesses	2	12	6
Welsh Rags and Imperials	3	13	6
Westmoreland	4	14	6

Slaters' work, for galleries, varies, according to the mouldings, from 4*s.* 6*d.* to 5*s.* 6*d.* per foot superficial; skirtings and facings from 1*s.* 6*d.* to 2*s.* per foot. Chimney-pieces, &c. are sold at so much per piece.

391.—EXPLANATION OF THE TERMS USED IN SLATING.

Back of a Slate.—The upper side of it.

Backer.—A narrow slate put on the back of a broad square-headed slate when the slates begin to get narrow.

Bed of a Slate.—The lower side of it.

Bond or Lap of a Slate.—The distance between the nail of the under slate, and the lower end of the upper slate.

Eave.—The skirt or lower part of the slating hanging over the naked of the wall.

Holing.—The piercing of slates for the admission of nails.

Margin of a Course.—Those parts of the backs of the slates exposed to the weather.

Nails.—Pointed iron, or copper, or zinc, of a pyramidal form, for fastening the slates to the laths or boarding. They are commonly of the description or shape of clout-nails.

Patent Slates.—Those which are used without boarding, and screwed to the rafters, with slips of slates, bedded in putty, to cover the joints.

Scantle.—A gauge by which slates are regulated to their proper length.

Sorting.—Regulating slates to their proper length by means of the scantle.

Squaring.—Cutting or paring the sides and bottom of the slates.

Tail.—The bottom or lower end of the slate.

Trimming.—Cutting or paring the side and bottom edges of a slate, the head of the slate never being cut.

BOOK V.

PLUMBING, PAINTING, AND GLAZING.

CHAPTER I.

PLUMBERY OR PLUMBING.

392. Plumbery comprehends the practice of casting and laying sheets of lead, also making and forming pumps, cisterns, reservoirs, water-closets, &c. The ductility of lead enables the plumber to effect his operations by means of tools, few in number, and simple in construction.

393. Lead, the metal in which the plumber chiefly works, is distinguished for durability and malleability. It is a white metal of a considerable blue tinge, very soft and flexible, not very tenacious, and consequently incapable of being drawn into very fine wire, though it is easily extended into thin plates under the hammer. Its specific gravity is 11·35.; it melts at 612°, in a strong heat it boils and emits noxious fumes. Lead is brittle at the time of congelation. In this state it may be broken into fragments with a hammer.

Lead is not much altered by exposure to air or water, though the brightness of its surface, when cut or scraped, very soon goes off. It is probable, that a thin stratum of oxyde is formed on the surface which defends the rest of the metal from corrosion.

Every kind of metal becomes more difficult of corrosion or oxydation when its specific gravity is increased by condensation, this may be effected either by the hammer or passing it through rollers. Sheet-lead is used in two distinct states by plumbers, the first is that in which it is cast, and in this state it is applied as a covering to the flat-roofs, gutters, and other parts of buildings, also for lining cisterns or reservoirs where water is kept. In architecture, it is technically divided into 5, 5½, 6, 6½, 7, 7½, 8, 8½ lbs. cast-lead, by which it is understood that every foot superficial of such cast-sheet lead is to contain one or other of these weights.

394. Large sheets of lead are cast in the following manner:—The lead destined for this use is melted in a large cauldron or furnace, formed mostly of free-stone. At the bottom, a place is sunk lower than the rest in which is placed an iron pot or pan to receive what may remain of the metal after the sheet is run. The furnace is so raised above the area of the floor, as that

the iron pot just rests upon it. In using the furnace, they heat it with wood, which is placed within it and ignited, and then the lead is thrown in at random with the burning fuel to melt.

Near the furnace is the table or mould on which the lead is to be cast. This is formed of large pieces of wood well jointed, and bound with bars of iron at the ends. Around it runs a frame or ledge of wood three inches thick, and about two inches high from the table, technically called the *sharps*. The ordinary width of the tables is from three to four feet, and their length from eighteen to twenty feet.

This table is covered with a stratum of fine sand slightly moistened with water, taking care to use no more than will just make it bind together when closely pressed. The sand in this state is closely compressed by beating it with a mallet, the surface being reduced to a plane by a straight edge of brass or wood.

Over the table is a strike or rake of wood which bears and plays on the edges of the frame, by means of a notch cut in either end of it, and is so placed as that, between it and the sand, is a space proportionable to the intended thickness of the sheet of metal to be cast. This strike is used to drive the metal, while yet liquid, to the extremity of the mould.

At the top of the table is a triangular peel or shovel, bearing before on the edge of the table itself, and behind on a kind of tressel, somewhat lower than the table; its use is in conveying the metal into the mould, and the design of its oblique disposition is, that it may by that means be able to retain the metal, and keep it from running off at the fore-side, where it has no ledge, some of these peels are large enough to hold fifteen hundred weight.

When the apparatus is thus disposed, with a large iron ladle they take the melted lead, coals, and all out of the furnace, and with this, mixed as it is, they fill the iron peel. When full, they take out the coals, and clean the lead with another iron spoon, pierced after the manner of a scummer; they then hoist up the lower part of the peel by its handle, upon which the liquid matter running off, and spreading itself upon the mould, the plumber conducts and drives it to the extremity of the table by means of the strike, which he passes along the ledges, and thus renders the sheet of an equal thickness. The sheets thus cast, there remains nothing to do, but to planish the edges on both sides, in order to render them smooth and straight.

Where it is desirable to increase the durability of lead, as in the cases of being very much exposed to sun or wet, it is now usually rolled between the rollers of a flatting mill. The lamination increases the specific gravity of the metal, and makes it resist oxydation much longer. This process is performed most commonly at the furnaces where the ore is reduced, the rollers being of immense dimensions, and requiring great power to drive them.

395. Lead Pipes are universally employed for small water-pipes, chiefly from the facility of bending them in any direction, and also the capability of soldering their joints. Although some kinds of water corrode the metal by degrees, this will not produce so much harm as iron under the same circumstances, but would be a most dangerous poison if it was used in sufficient quantities to have any effect at all.

The method now very generally adopted in the manufacture of leaden pipes, is to cast the lead in an iron mould, upon a cylindrical iron rod of the size for the bore of the intended pipe, the lead being three or four times the thickness of the intended pipe; and in short lengths, which are then drawn through holes in pieces of steel, in the manner of wire drawing, till the pipe is reduced to the intended thickness, and drawn out to the proper length. Another method is to reduce the pipe by repeatedly passing it through the two rollers of a flatting mill, in each of which a number of semi-circular notches or grooves are formed all round, so that the two rollers when put together, have a number of circular cavities between them, which gradually diminish in diameter from one end of the rollers to the other.

The pipe is first rolled between the largest of these cavities, then in a smaller one, and so on to the last, which extends the pipe to its proper length, and diminishes its substance to the proper thickness, at the same time, by condensing the metal, hardens it, and makes a very strong tube with very little metal. Mr. John Wilkinson, of Broseley, obtained a patent, in 1790, for the last named method, which he practised on a very extensive scale. Since the expiration of this patent, many manufactories of this article have been established, some employing rollers, and others the draw-bench for extending the pipes.

396. Solder is used for uniting the joints of leaden work, and it should more readily acquire a state of fusion than the metal intended to be soldered thereby, and be of the same colour. The solder generally made use of by the plumber, is called *soft solder*, and is made of tin and lead, in equal parts, fused together, and run into moulds like a common gridiron; in this state it is purchased of the manufacturer by the plumber at so much per pound, according to the price of the market.

397. Laying of Sheet Lead. The ground for sheet lead, whether it be of plaster or boards, should be perfectly even, otherwise the work will be bad, unsightly, and liable to crack. The sheets not being more than six feet in width, make it necessary that they should sometimes be joined; this is performed either by *seams* or *rolls*. The seams are formed by bending the two edges of the lead up, and over each other, and then dressing them down close. The rolls are formed by fastening a piece of wood about two inches square under the joints of the lead, and dressing one of the edges of the lead over the roll on the inside, and the other edge over both of them on the outside, and then fastening them down by hammering. Soldering is sometimes used for joining two sheets; but this mode should be rejected on account of its liability to crack when exposed to alternate expansion and contraction, occasioned by heat and cold. All sheet lead should be laid with a *current* to keep it as dry as possible; and for this purpose the boarding or ground upon which it is laid, should have a fall of about one quarter of an inch to every foot upon which the lead is laid.

398. Drips on Flats or Gutters are formed also in the preceding manner, and by dressing the joints of the lead as described for rolls. This is used to avoid solder, and keep the work dry.

399. Flashings are pieces of milled lead about eight or nine inches wide, and are fixed round

the extreme edge of a flat or gutter in which lead has been used. One edge is dressed over the lead of the flat or gutter, and the other fastened, either by passing it into the joints of brick work, or fixing it by means of wall-hooks.

The pipes used by plumbers vary, in the diameter of their bores, from half an inch to two inches. Socket pipes are those which are used for conveying superfluous water from roofs, &c., and are usually from three to five inches diameter. These are made of milled lead, in lengths of eight or ten feet, dressed on a cylindrical core of wood, and fastened at the vertical joinings with solder; the horizontal joints are formed by an astragal moulding in a separate piece of lead, about three inches wide, which laps completely over it, both above and below the joint, and hence it is called a *lap-joint*. Two broad pieces of lead, called *tacks*, are attached to the back lap joints, and spread out right and left for fastening the pipes to a wall by means of wall hooks. The cistern head, which is fixed to the upper end of rain-water pipes, is either made of sheet lead, or cast in a mould, and fastened by tacks as above described.

400. Pumps. Those supplied to the public by plumbers are usually made by engineers, who have suitable apparatus for boring the barrels, they being made of brass, or metal very similar in its nature. They may be divided into three distinct kinds, namely, *Sucking*, *Lifting*, and *Forcing* Pumps. Forcing pumps are now but little used; the lifting and sucking pumps being proved by experience to be the best for most domestic purposes. The sucking pump consists of two pipes, the barrel and suction pipe, the latter being smaller in diameter. These are joined by flanches, having leather placed between them to make the joints water-tight. The flanches are united by screw-bolts in the usual manner. The lower end of the suction pipe is spread out, or made funnel-shaped to facilitate the entry of the water, and it frequently has a grating to keep out filth and gravel. The working barrel is cylindrical, and as evenly bored as practicable, to give the piston the least possible friction.

The *Piston* is generally made of wood in the form of a truncated cone, the small end being cut off at the sides so as to form a kind of an arch, by which it is fastened to the iron rod or spindle; the two ends of the conical part may be hooped with brass, and the larger end of the cone uniformly surrounded with leather to some distance below its base. This leather band should be sufficiently large to render the piston air tight, without causing unnecessary friction.

The *Lifting Pump* consists, as in the former, of a working barrel, which is closed at both ends. The piston is usually solid, and its rod passes through a collar of leather, or a stuffing box, in the plate, which closes the upper end of the working barrel. The barrel communicates laterally with the suction pipe, and above with the rising main. This pump differs from the preceding only in having two valves, the lower one moveable, and the upper one fixed.

In Plate XXXIX. fig. 2, represents an elevation, and figure 3, a vertical section, of a very perfect lifting pump, as now made by Messrs. Bramahs, the celebrated engineers, at Pimlico; the construction of the various parts as explained by the section, will show the extent of water-way that has been here obtained by the excellent construction and disposition of the valves, and also

the superior means applied in the upper part for keeping the piston rod lubricated with oil. The excellent proportions of all the parts, and the judicious combination of the whole, induced us to give the two figures before-named for the benefit of our practical readers, who will here have an opportunity of examining the internal construction engraved from a working drawing, very kindly furnished us by Messrs. Bramah and Sons, for this work.

The *Forcing Pump* consists of a working barrel, a suction pipe, and *serving main*, or raising pipe. The last is usually in three parts; the first consisting of one piece, and making part of the working barrel; the second is joined to it by flanches, forming an elbow with it; and the third is the beginning of the main, and is continued to where the water is delivered, where it is furnished with two moveable valves. The perfection of the barrel and piston of this pump is so great as to require neither wadding nor leather; it is only used where it is found requisite to force water to a considerable height.

There are a considerable variety of pumps besides those above described, but none of them are so applicable to domestic purposes or general use, as those we have enumerated.

The materials of these pumps are manufactured to almost every required purpose, and thus sold to the plumber, who only puts them together so as to make them produce their desired effects.

The different parts of *water-closets* are made in a similar way, and sold to the plumber, who places the basin, apparatus, traps, socket pipe, cistern, and forcing or lifting pump together, so as to put them in action.

Sheet lead is charged by the hundred weight, according to prices arranged at intervals by the Warden and Court of Assistants of the Plumbers' Company. Milled lead is usually charged two shillings per hundred weight more than cast lead. The best method of preserving lead when exposed to the action of the atmosphere and water, is to place iron in close contact with it; the galvanic effect produced causes the iron to be oxydized, the lead being preserved almost entire, while there is iron in contact with it.

401. The tools of the plumber are few in number, and simple in construction. The following enumeration will be deemed sufficient:—

Centre Bits, of various sizes.

Chalk Line, used in the same manner as a carpenter's.

Compasses, are used for striking out circular portions of lead.

Cutting Knives, of various sizes; these are used for dividing sheet lead at the mark left by the chalk line.

Dressing and Flatting Tool.—This is made of beech, about eighteen inches long, and two and a half square; planed smooth on one side, and rounded into an arch on the other. It is used for stretching out and flattening the sheet lead, or dressing it into any required shape.

Files, of various sizes.

Glasing or Heating Irons, of various sizes; about twelve inches long, and tapering at both

ends, the handle end being turned quite round, that it may be held firmly in the hand. The opposite end is spindle shaped. These are used red hot in soldering.

Hammer, made of iron, which is rather heavier than those in general use.

Ladles, made of iron; these are of various sizes, and are used for melting solder in.

Mallets, similar to the carpenter's, of various sizes.

Jack and Trying Plane for finishing the edges of sheet lead.

CHAPTER II.

HOUSE PAINTING.

402. House Painting is that *economical* application of artificial colours, compounded either with oils or water, which is employed in preserving or embellishing houses, ships, furniture, &c. The term economical painting may with propriety be applied to the property which oil and varnishes possess of preventing the injurious effects of the atmosphere upon wood, iron, and stucco, by interposing an artificial surface or covering composed of materials, which, by the peculiar chemical changes effected in them, are rendered capable of resisting the decomposing and destroying qualities of the atmosphere, and thereby of preserving various substances from premature decay. It is here intended to use the term more generally, in allusion to the decorative part, as applied to buildings, as well as to its more essential ones, and as it is employed by the architect throughout every part of his work, both externally and internally.

The chemical properties of the materials, and the mode of applying them is the same, either in churches, theatres, or any other public or private buildings, or with such slight variations, as will be readily suggested by a judicious workman. We shall now describe the principal pigment used as a base in all house painting, and also the vehicles most commonly used to mix and dilute the colours with.

403. White Lead is the principal ingredient used in house painting, forming the basis of most of the neutral colours. It is obtained by rolling thin sheets of lead into coils, leaving their surfaces about half an inch apart from each other, and then placing them vertically in earthen pots, with a portion of good vinegar at the bottom, in such a way, that when set in a moderate heat, the vapor of the acid oxydates the lead, producing a carbonate of lead, which may be taken off in white flakes when the sheets of metal are uncoiled. These flakes are then ground in linseed oil, in which state it is sold in the market by the name of *white lead*. The materials so combined are much better for being kept, and where the best and purest whites are required to be produced, it should be kept in the levigated state for at least two years. The Nottingham white

lead is most esteemed for whites, without gloss, commonly or technically called flatting or dead white.

404. Linseed Oil is expressed from the seed of flax, by those who manufacture it, in large quantities. It is the principal oil used in house painting. The worst defect of this oil is its natural brown colour, and a tardiness in drying. The goodness of linseed oil, therefore, consists in its near approach to a colourless state, and in its drying soon. It may, however, be used in its simple state, by simply mixing with it some substance which will increase its drying properties. But keeping it for some considerable time, will be found to improve its qualities both for colour and also drying. These effects will be greatly promoted by exposing it to the action of the atmosphere and light, both of which tend to bleach and improve it. This oil may be rendered much more capable of drying, by boiling it with certain substances, such as red lead, white vitriol, sugar of lead, umber, and many other substances; but all of these have a tendency to increase its natural colour, and if carried to a considerable extent, render it very nearly black, owing, in a great degree, to particles of the oil being completely carbonized.

405. Boiled Oil may be prepared by adding to each gallon of linseed oil one pound of litharge, one pound of white vitriol, half a pound of sugar of lead, and a quarter of a pound of umber; boil them so long as the discolouring the oil will permit, for the oil must not be boiled so long as to produce blackness. When the oil is taken off the fire, it may while hot be strained through flannel, after any indissoluble portion of the ingredients have settled.

406. Oil of Turpentine is an essential oil, distilled from crude turpentine, and is technically called by the painters *Turps;* it quickly exhales or evaporates in the air, and if mixed with linseed, nut, or poppy oils, in flying off, carries with it the more volatile parts of such oils, and causes them to dry much sooner than they otherwise would do. On this account it is very generally used as a dryer to mix with the other oils, for which purpose it has greatly the advantage over drying oil with regard to colour, as it is perfectly transparent and pellucid.

It is used without any other preparation than mixing it, either alone or together with drying oil, along with the other oils and colours; and it is not subject to any adulteration, except the dissolving crude turpentine or resin in it, which do not greatly injure it for the purposes we are describing. It should, however, be observed, that for all the purposes of painting it will be the better for age; its valuable quality for drying being greatly increased by that circumstance.

407. Litharge is an oxyde of lead, prepared in the process of refining gold and silver. It is used in making drying oil, in the manner above described.

408. Sugar of Lead is a chemical preparation of lead, made by dissolving it in vinegar, and reducing the salt to a crystalline state. It has a quality of making oils dry when mixed with them, and on that account is very frequently used, as well in the manufacture of drying oil, as in the common use of the oils, where it is ground up with them, together with the colours. It is also kept ready ground with oil, and sold in a state ready to mix with colours at any time.

409. White Vitriol, or sulphate of zinc, is commonly used as a dryer. It is found as a

mineral substance in various parts of Europe, and may be made artificially by a peculiar application of sulphuric acid to zinc. It is much used in making drying oils, and also when ground with oil, and mixed with colours, to render the oil drying.

410. *Putty* is a compound of whiting and linseed oil, but the best is that made with drying oil that has been very much boiled, by the use of which a composition may be formed, that will become sufficiently hard, but will yet be tough, without being so brittle as that which is made of common linseed oil without boiling. In all cases, the oil should be thoroughly mixed with the whiting, and the more it is worked together the better it will be; and for this purpose, some manufacturers have used a kind of mill to facilitate the operation.

411. The first coatings or layers, if on wood or iron, ought always to be of white lead, the very best that can be obtained, great care being taken to procure that which is thoroughly ground; but previous to laying the first coat upon fir or deal of any sort, it will be requisite to destroy the effects of the knots. These are, in general, so thoroughly saturated with pure turpentine, as to render it one of the most difficult parts of the house painter's art to conquer; indeed it may be truly said, to remain at the present time a desideratum. The usual method is to dab them over with a mixture of white lead ground in water, having a portion of red lead mixed therewith, the liquid vehicle being parchment size; when this is dry, they should be separately painted over with white lead ground in oil, to which some powerful drier has been added, as red lead or litharge, about one-fourth of either being the usual quantity. These preparations should be smoothly finished with the brush, in the direction of the grain of the wood. When the two coats are dry, the parts so treated should be rubbed over with pumice stone to make them equally smooth with the other parts, and then the first coat of paint should be laid on, the colour being rendered sufficiently liquid with linseed oil. The first coat being dry, all the nail-holes and other imperfections should be filled up or stopped with putty, the surface being left perfectly smooth. The work may then receive a second coat of white lead and oil, somewhat diluted with the essential oil of turpentine, and this should be repeated twice at least, forming three coats in all, but in very fine works a fourth is sometimes added. Where it is intended the work when finished should not be of a perfect white, the last coat should have a small quantity of ivory or lamp black added, to reduce the whiteness in a slight degree, which will produce a very pleasing effect, and will be found very serviceable in preventing the change of colour which frequently takes place from the oil not being of sufficient age. The usual proportion of turpentine to oil is about one-fourth of the former to three of the latter, which will produce a glossy or shining surface; but where the surface is required to be without gloss, as in all the better sorts of work, and which is technically called *flatted*, then the colour, whether it be pure white or any compound tint, must be made sufficiently thin with turpentine, and when used in that state, it will dry without any gloss upon the surface, and consequently reflect to the eye of the beholder one uniform *flat* tint. It may be requisite to observe here, that as the colour mixed with a large proportion of oil dries much slower than where

a large proportion of turpentine is used, little difficulty is experienced in laying it on large surfaces perfectly even, the one part blending into the other very easily, but, in *flatted* work, considerable management is requisite, as well as considerable activity, on account of the rapid drying of the colour; and for this purpose, where the sides of very lofty apartments are to be covered in that manner, it is frequently necessary to have two persons employed at the same time, upon nearly the same part. The best mode of proceeding is to begin at the top of the right hand side of the compartment to be flatted, taking care not to cover a larger stripe or portion than can be completely effected before the upper part becomes dry; and if this be properly accomplished, the joinings will not be visible; but where the sides of a room are too lofty for one person to effect the object in time, then two must be employed to ensure success, it being almost impossible to produce a flat tint, where a new portion is joined upon a part already dry, or nearly so. It must also be observed, that two coats in oil, and then two in turpentine, are necessary for all new work that is to be well executed. Flatted work, owing to its want of gloss, is more likely to soil by being touched, than work executed in oil; but its superior delicacy, and also the property it has of retaining its colour, renders it indispensable for all situations where delicacy and durability of colour are necessary. It should, however, be observed, that as a very small portion of oil is used, namely, that only that is necessary to grind the colour with, it is inapplicable to parts that are exposed to the weather, preservation being in that case the principal object.

What has been here stated may suffice as to painting on wood, either on outside or inside works; the former being seldom executed otherwise than in oil, three or four coats being generally quite sufficient. But as the painting of stuccoed walls (not previously painted) require considerable care, we shall now offer such observations and directions as, if attended to, will render that department easy and certain of attainment.

412. In order to succeed in painting stucco, not only the plastered surface should be thoroughly dry, but the brick-work upon which it is laid should also be completely free from damp or moisture, which can only be the case where the walls have been erected a sufficient time to permit the mass to attain perfect dryness. Indeed, the greatest part of the mystery of painting stucco, so as to answer the intended purpose of standing and wearing well, consists in attending most scrupulously to these observations, for whoever has observed the expansive power of water, not only in congelation, but also in evaporation, must be well aware, that when it meets with any foreign body obstructing its escape, as oil-painting for instance, it immediately resists it, forming a number of vesicles or particles, containing an acrid lime-water, which forces off the layers of plaster, and frequently causes large defective patches, extremely difficult to be repaired. In those works where persons have an interest in the durability, two years is certainly not too long a time to thoroughly dry both the walls and plaster; but in speculative works, even a few weeks are scarcely allowed, and hence the bad appearance of such works in such a very short period of time after they are executed.

If these precautions be duly attended to, there can be no better mode adopted for priming or laying on the first coat on stucco, than by using boiled linseed oil, prepared as above-described, taking care to lay it on very evenly, so as to leave the surface very smooth, and not more than the stucco will absorb. It should then be covered with at least three coats of white lead and oil, taking care to let two or three days intervene between each coat.

If the stucco be intended to be finished of any given tint, as grey, light green, apricot, &c., it will then be proper about the third coat of painting, to prepare the ground for the desired tint by a slight advance towards it.

Grey is made with white lead, Prussian blue, ivory black, and lake. Sage green, pea and sea greens, with white, Prussian blue, and fine chrome yellow. Apricot and peach, with lake, white, Chinese vermilion and chrome yellow. Fawn colour, with burnt terra sienna or umber and white. Olive greens, with fine Prussian blue and Oxfordshire ochre.

In some cases it may be absolutely necessary to inhabit buildings before the walls are sufficiently dry to receive a coating of oil paint; the colouring in distemper must then be resorted to, which being a covering of water-colour fixed by size, may be washed off and completely removed at any time when the walls are considered to be perfectly dry and fit to receive the oil colour.

413. Distemper. In this kind of painting, the white colour or base most commonly used is the finest whiting, which is prepared in large quantities by various manufacturers. The colours most commonly mixed with it for producing the various tints are as follows:—Straw colour, may be made with white and masticot or Dutch pink; fine greys, with white and refiner's verditer; an inferior grey may be compounded with blue black or bone black, and damp blue or indigo; pea greens, with French green, Olympian green; and fawn colour, with burnt terra sienna or burnt umber and white, and so of any intermediate tint. All the colours used in distemper, should either be ground very fine, or washed over so as to ensure the most minute division of their particles. In general, the size made of common glue is used with a proper quantity of water to render the colour liquid, but where the work will afford it, parchment size will be found greatly superior.

It will not require less than two coats of any of the foregoing colours, in order to cover the plaster, and bear out with an uniform appearance.

When old plastering has become discoloured by stains, and it be desired to have it painted in distemper, it is then advisable to give the old plaster, when properly cleaned off and prepared, one coat at least of white lead ground in oil, and used with spirits of turpentine, which will generally cover all old stains, and when quite dry will take the water colours very kindly. The above process will also apply to old wainscotings, in cases where temporary painting is only required; but of course such a method cannot be recommended for durability.

In every kind of painting, but particularly in oil-painting, the greatest degree of cleanliness should be rigidly enforced. The brushes and all the utensils should be freed from the portions of paint that will dry upon them from time to time, by scraping and washing, which may be done

with a blunt knife and strong soap and water, for if this be not done, the colours will soon become very foul, and the work will in such cases be very inferior.

414. Graining. This is a kind of ornamental painting, lately used to a considerable extent in the decoration of houses. It consists of imitating, by means of painting, various kinds of rare woods, as satin-wood, mahogany, rose-wood, &c., and likewise various species of marble. For this kind of work the painter is furnished with several camels' hair pencils, and with one or more flat hogs' hair brushes. An even ground is first laid of a mixture of white lead, and the colour required, diluted with oil of turpentine. This is left for a day or two to get thoroughly dry. The painter then prepares his palette-board with small quantities of the colour required, and having some boiled oil and turpentine mixed together, tries the effect of the tint by spreading it over a panel, and if it suits, perseveres by doing a single panel at a time. The shades and graining is then produced by dipping the flat hogs' hair brushes in the mixture of oil and turpentine, and drawing it down the newly-laid colours. The other particular appearance required, is produced by means of the camels' hair pencil. When all is fixed and dry, the whole is covered with one or two coats of good oil varnish. This kind of painting is not much dearer than good work in the common way, but it will last ten times as long by being occasionally varnished, without losing any of its freshness.

CHAPTER III.

GLAZING.

415. On glass very little has been communicated in the works of the ancients. It, indeed, appears, from the ruins of several Grecian buildings, that they had apertures or windows; and it would seem, from the nature of their construction, they were adapted to receive a frame filled with some transparent substance. In some of the apertures discovered at Pompeii and Herculaneum, squares of amber were found; yet, though many of the Roman authors mention glass, it was so rare as to be employed only in the mansions of the opulent.

Bede is the first who mentions glass as applied to glazing windows. He likewise informs us that Abbot Benedict was the first who introduced the art of making glass into this kingdom, about the year 669; and, from the specimens that now remain, it is evident that not only the making of glass, but the art of staining it, made rapid strides towards perfection in a very short time after.

Glazing, as now practised, embraces the cutting of glass, and fixing it into sashes of wood or casements of lead and likewise the ornamenting of windows with stained glass.

Plain coloured glass may frequently be used with a very pleasing effect, and is very little more expensive than good common glass. Coloured glass is charged by the pound; Claude Lorraine, green, red, &c., at about six or seven shillings, and blues somewhat more.

Glazing in lead-work is of the most antient description; sashes being of modern date. These sashes are formed with a groove or rebate, on the back of their cross and vertical bars, for the reception of the glass, which the glazier cuts to its proper size, and beds in the composition called *putty*.

Putty is made of pounded whiting, beat up, with linseed oil, into a tough tenacious cement. When used for mahogany frames, a little red-ochre is mixed with it to suit the colour of the wood.

The beauty of glazing depends principally on the colour of the glass. Glaziers now use chiefly what is called *crown glass*, which is divided into three kinds, called *firsts*, *seconds*, and *thirds*, according to their qualities, on which its value depends. The glass is bought by the crate, which consists of twelve tables of the best, fifteen of the seconds, and eighteen of the thirds. These tables are each about three feet in diameter. A crate of the best glass is valued at about four guineas; of the seconds, about three; and the thirds, two guineas. The crown glass manufactured at Newcastle and its neighbourhood is esteemed the best: the prices of glass are various.

Green-Glass is another sort, much used for common purposes, being not more than half the price of the crown-glass. From many old windows, it appears that this kind of glass was the most antient made use of.

Waved Plate-Glass is very thick and strong, presenting an uneven surface, as if indented all over with wires, so as to leave the intermediate spaces in the form of lozenges; it was formerly much used in counting-houses, &c. to prevent the inconvenience of being overlooked; but though it has lately been superseded by ground-glass, it is still to be obtained in London.

Ground or *Rough Glass* is used for the same purpose as the above, and is no other than the common crown-glass, rendered opaque by having its polish taken off, and rubbing it with sand and water or emery.

Plate-Glass is the most beautiful glass made use of, being nearly colourless, and sufficiently thick to admit being polished in the highest degree. The tables of this glass will admit of pieces being taken out of them much larger than can be obtained from any other kind of glass. The British Plate-Glass Company, in Albion-Place, London, is the most celebrated depôt for this species. There it is sold by the inch, in proportion to its size, the value increasing accordingly. Though the expense of this glass, by far, exceeds that of any other, yet is now so much preferred, as to be used in many shop-windows in the leading streets.

German Sheet is another species of glass much esteemed, and would be superior to the preceding, had it not a disagreeable appearance, from being very wavy or uneven.

Bohemian Plate-Glass is similar to the above, only possessing a red tint; and though much used about thirty years ago, it is now quite rejected.

416. Glaziers value their work by feet, inches, and parts, according to the size of the panes, or squares, employed. The charges are regulated by the Master, Wardens, and Court-Assistants of the Company of Glaziers, and at present run thus:—

				s.	d.
Best crown, not exceeding 3 feet, per square				3	10
Ditto,	ditto	2 ft. 6 in.,	ditto	3	4
Ditto,	ditto	2 ft.	ditto	3	2
Ditto,	under	2 ft.	ditto	3	0

Seconds of the same dimensions are about ten per cent. cheaper; and

Thirds, of similar dimensions, are 10 per cent. cheaper than the seconds.

Green glass is the cheapest, never exceeding eighteen pence per foot.

The price of all kinds of bent glass, for circular and other windows, varies according to the size, the trouble of obtaining it, and fitting it in.

Cottage and some kinds of church windows are glazed in squares, or other figures, in leaden rebates, which are cast and drawn for the purpose, and soldered together at the interstices. This leaden work is of various sizes, according to the strength required, and is used instead of the cross bars of sashes. The grooves left in it for the glass have their cheeks sufficiently soft to be pressed down all round to admit the glass, and again raised up, when the glass has been put in, to keep it firm. Such windows are strengthened by vertical and cross bars of iron, with bands, which, having been soldered to the lead, are twisted round the iron. In cottage windows the bars, instead of being of iron, are often of wood.

417. Glaziers formerly cut their glass out with an instrument called a *grozing-iron;* but this process was not only tedious but difficult, and has therefore been entirely superseded by the introduction of the diamond, which is as complete a tool for the purpose as can possibly be required. This instrument consists of a diamond spark, in its natural *unpolished* state, fixed in lead, and fastened to a handle of some hard wood by means of a brass ferrule. The handle is about the size of a moderate drawing pencil. The diamond is the principal working tool of the glazier. His other tools are a rule and several small *straight edges*. The former is divided into thirty-six parts, or inches, and is used for dividing the tables of glass into any required size. The straight edges are merely thin pieces of some hard wood, about two inches wide, and one quarter of an inch thick, and are used for the diamond to work against. Glaziers are likewise furnished with *stopping knives*, which resemble dinner knives, with the blade reduced to about three inches in length, and ground away on each side of its edges to an apex. They are used for bedding the glass in the rebates, and for spreading and smoothing the putty.

A Hacking-out Tool is an old broken knife, ground sharp on its edge, and used for removing old putty out of the rebates, which are to be filled with new squares of glass.

The glazier's hammer is similar to the smaller kinds used by other artificers.

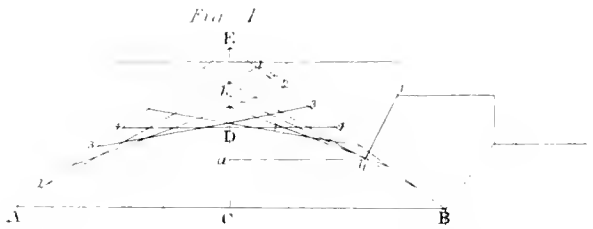
Glaziers are also furnished with a pair of compasses, which has one of its legs formed with a socket to receive the handle of the diamond, for drawing and cutting out any peculiar shapes of glass for fan-lights, &c.

Good glazing requires that the glass be cut full into the rebates; for, when too small or too large, it is liable to be broken by the least pressure within, or even the wind from without: moreover, the putty should never project beyond the line of wood in the inside, and large squares should be further secured by small sprigs being driven into the rebates of the sash, and covered over with another coat of putty.

The business of a glazier includes the cleaning of windows, and this forms no inconsiderable portion of the trade in London; some masters keeping one or two men constantly employed therein. The charge is regulated by the number of windows cleaned, and the number of squares in each frame. Windows, exceeding twelve squares, are charged from 6*d.* to 8*d.* per dozen, the large squares of French sashes being raised about one-third more. The master-glazier takes upon himself the risk of windows being broken by his men, when employed in cleaning them.

In many parts of the United Kingdom it is the custom to measure all the wood-work appertaining to the sashes, for the quantities of glass contained in the respective squares; also, the lead-work. And such is the prejudice in favour of the practice in some places, that if any intelligent person was to attempt to reason them out of it, he would be considered a most inequitable valuator, and unworthy of being countenanced. Time and concurring circumstances, it is presumed, may, at some period or other, equalize our customs, weights, and measures; but until that period arrives, the system of valuation must be dependent upon local customs. The net quantities of glass, should, in all cases, be measured, except in circular fan-lights and similar works, where the glass should be measured in the widest part; and because the pieces cut off to make the glass fit the apertures can be considered only as waste glass, the price or allowance for which is not embraced in the value charged by the glazier for his glass so consumed.

DESCRIPTION OF ARCHES.



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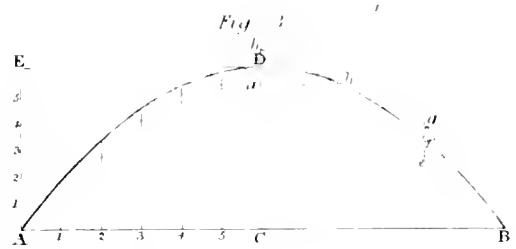

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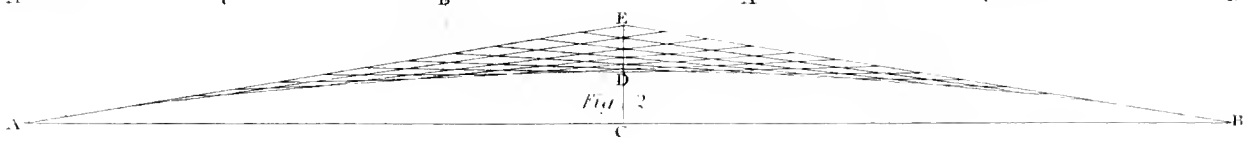

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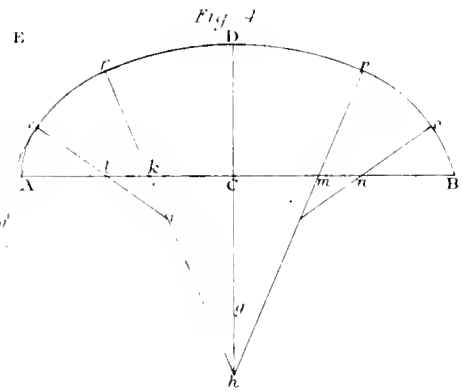

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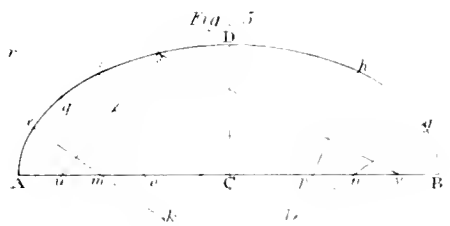

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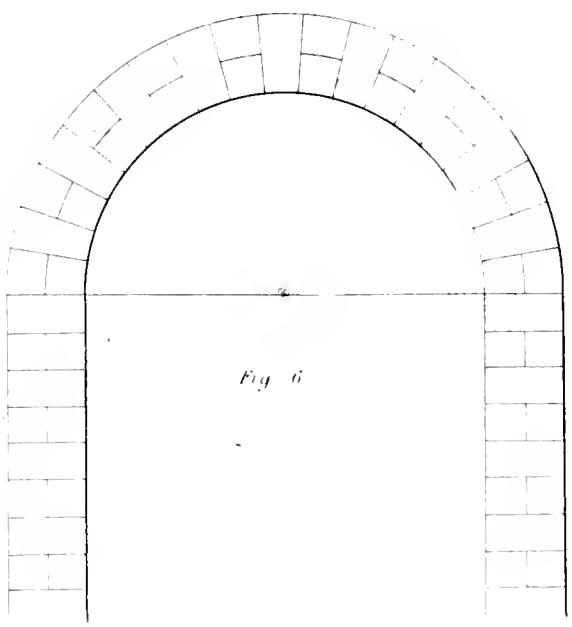


Fig. 6

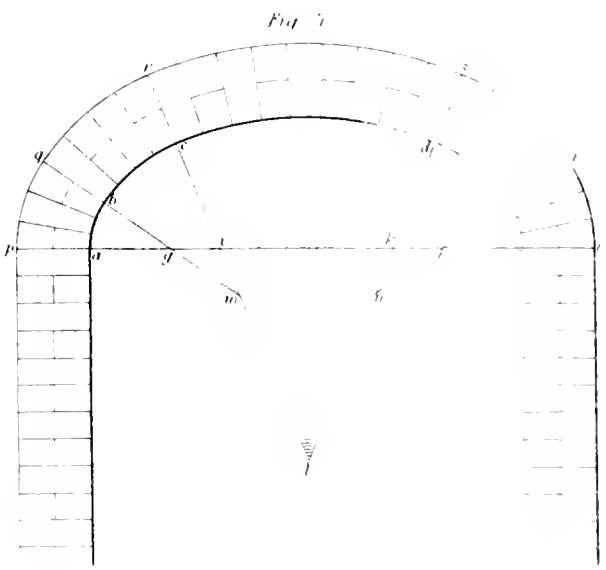


Fig. 7

Published by Thos Kelly 17 Paternoster Row April

CYCLOGRAPH.

Fig. 1

Fig. 1 N° 1

Fig. 2

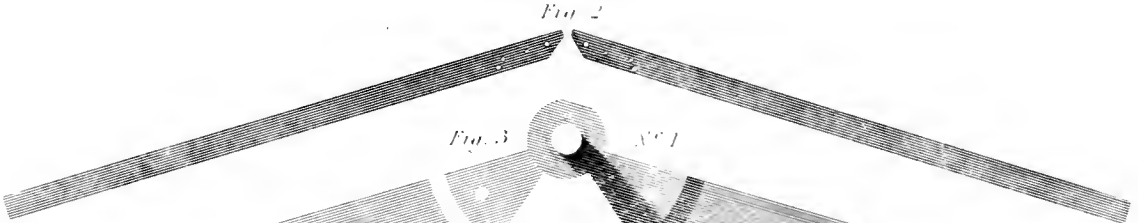


Fig. 3 N° 1

N° 2

Fig. 7.

Fig. 8

Fig. 6

Fig. 4

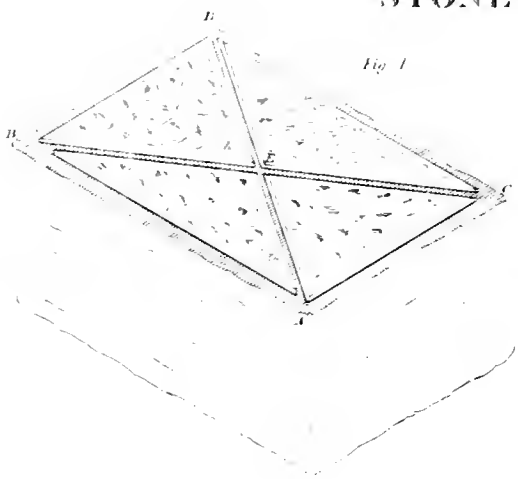
N° 2

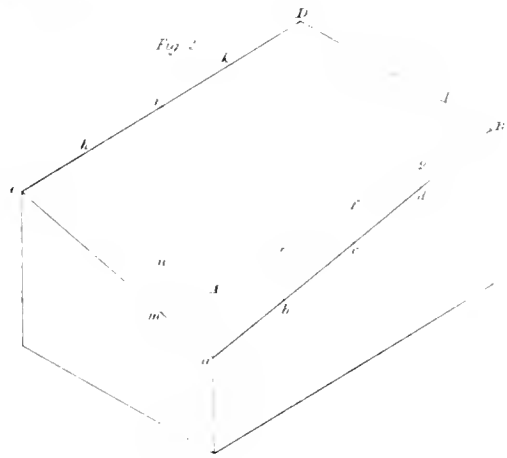
N° 1

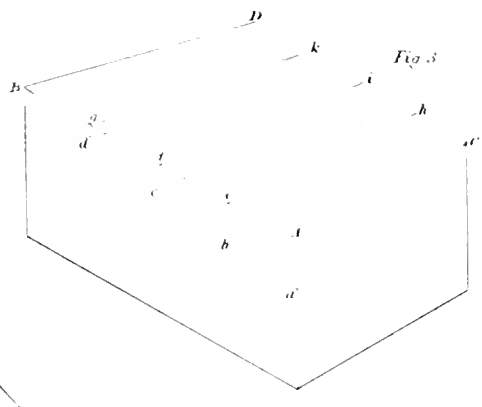
N° 3

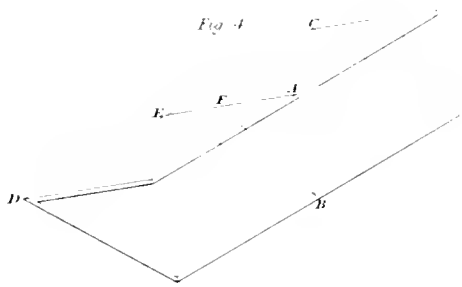
Fig. 5.

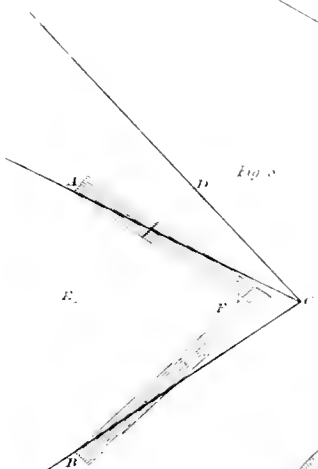
STONE CUTTING.

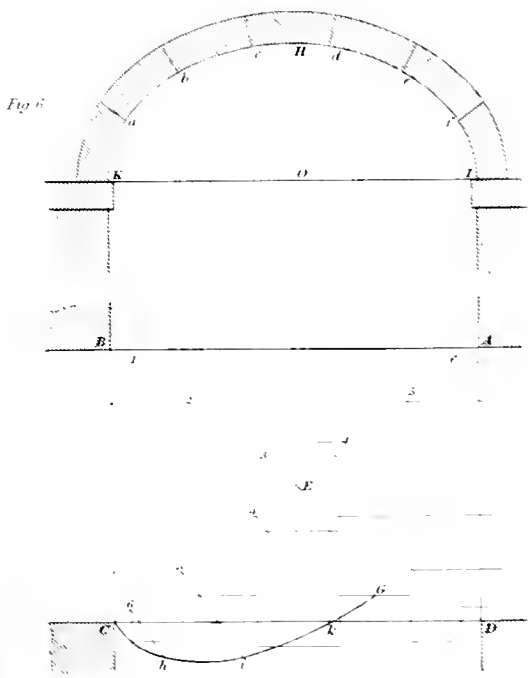












Published by The Kelly's Patent Stone Saw, July 5 '58.

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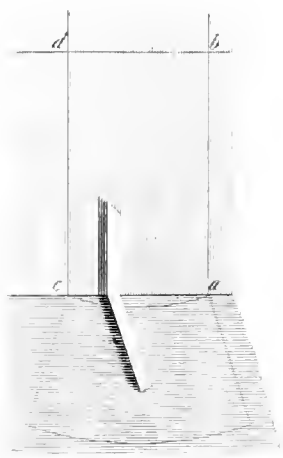

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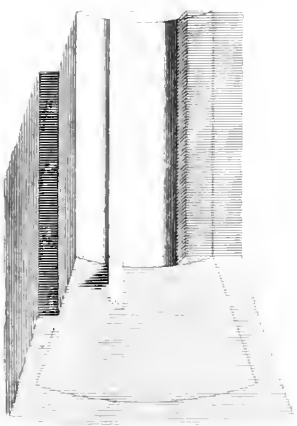

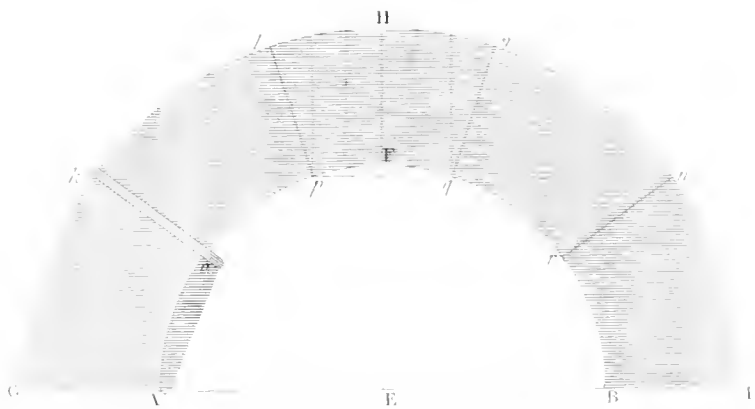

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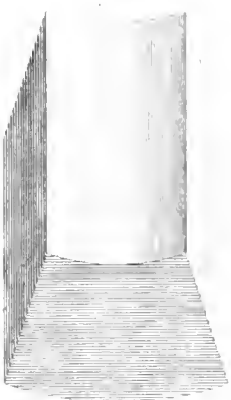

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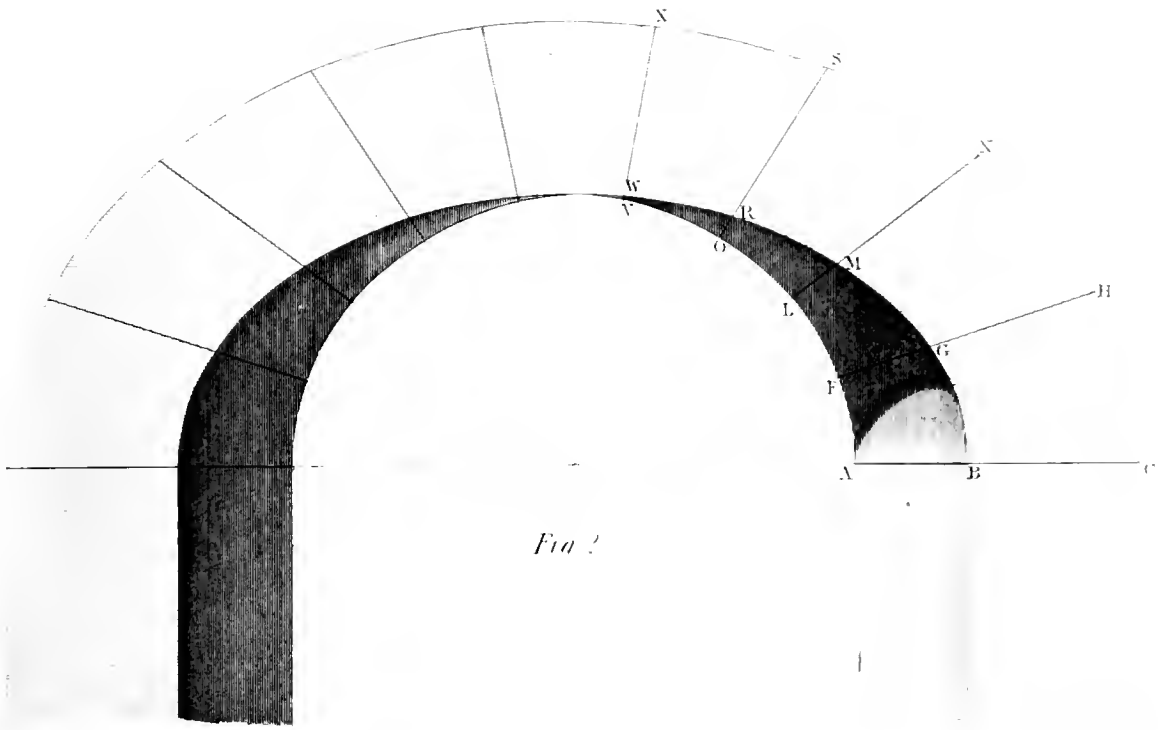

Fig 2

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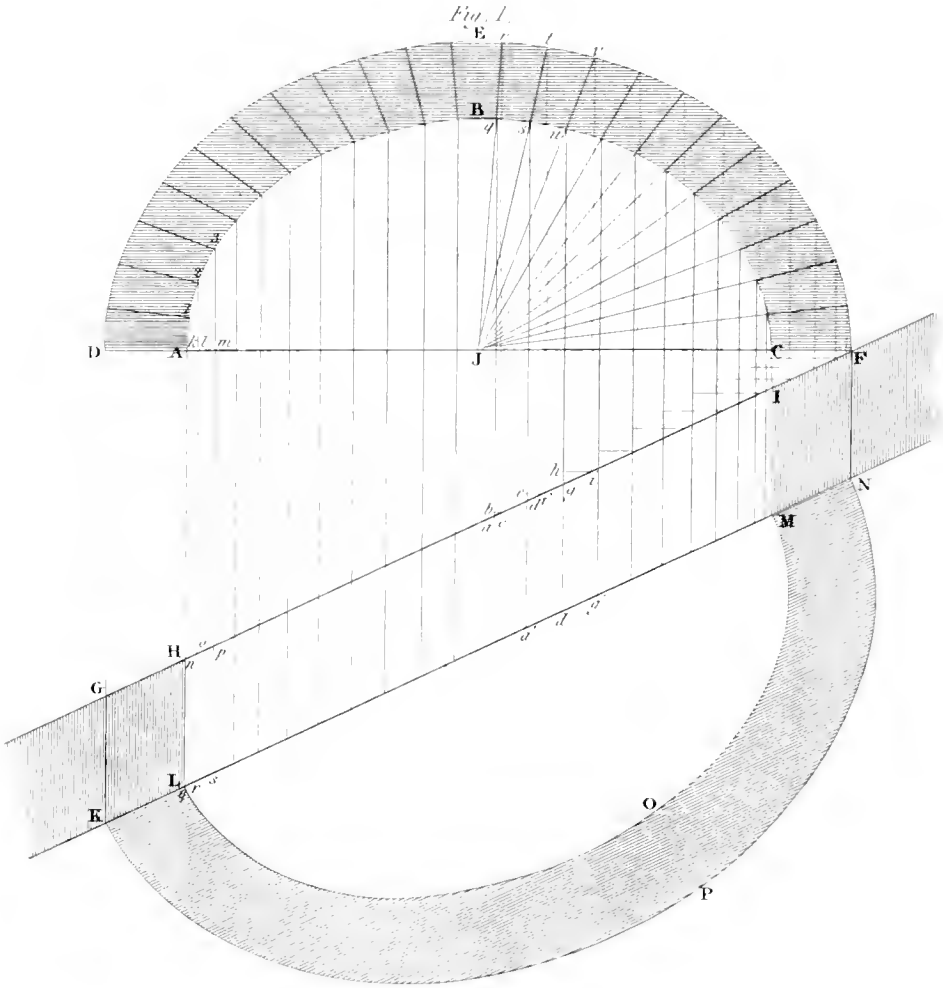
Fig. 1.



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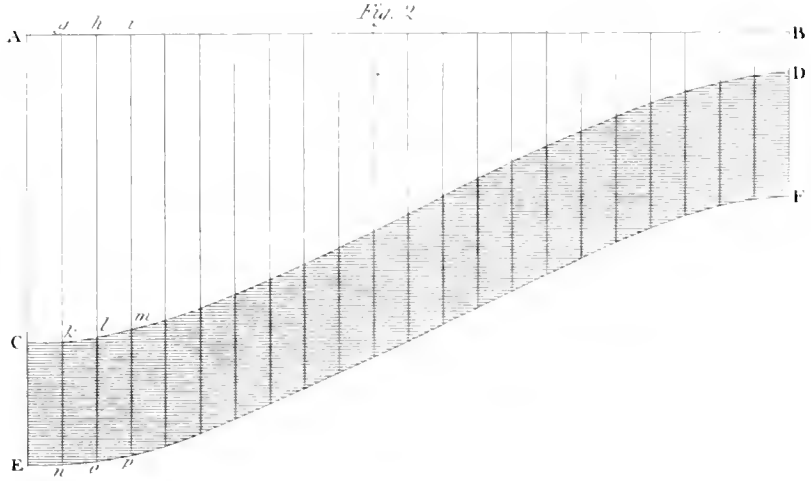

Fig 1

Fig 2

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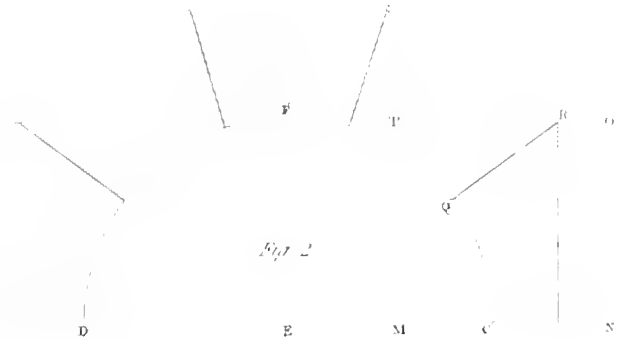

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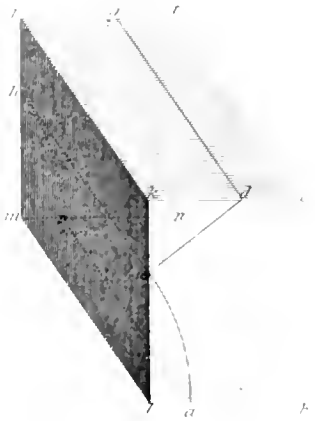

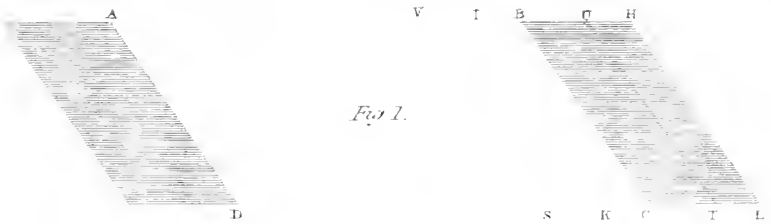

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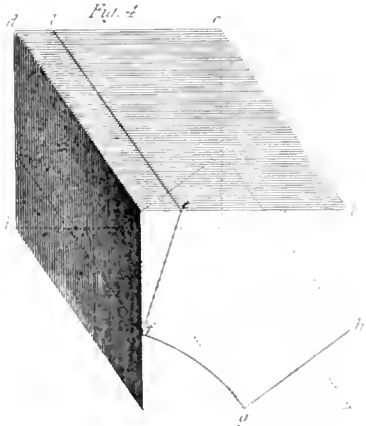

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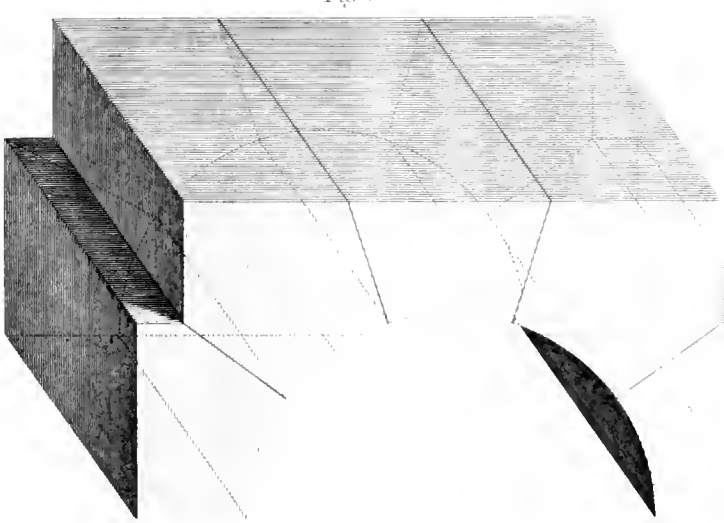

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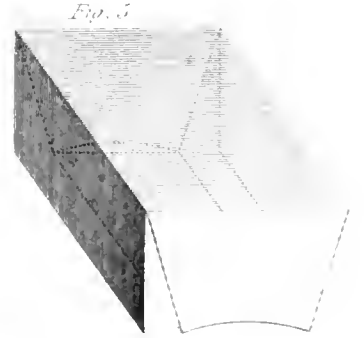

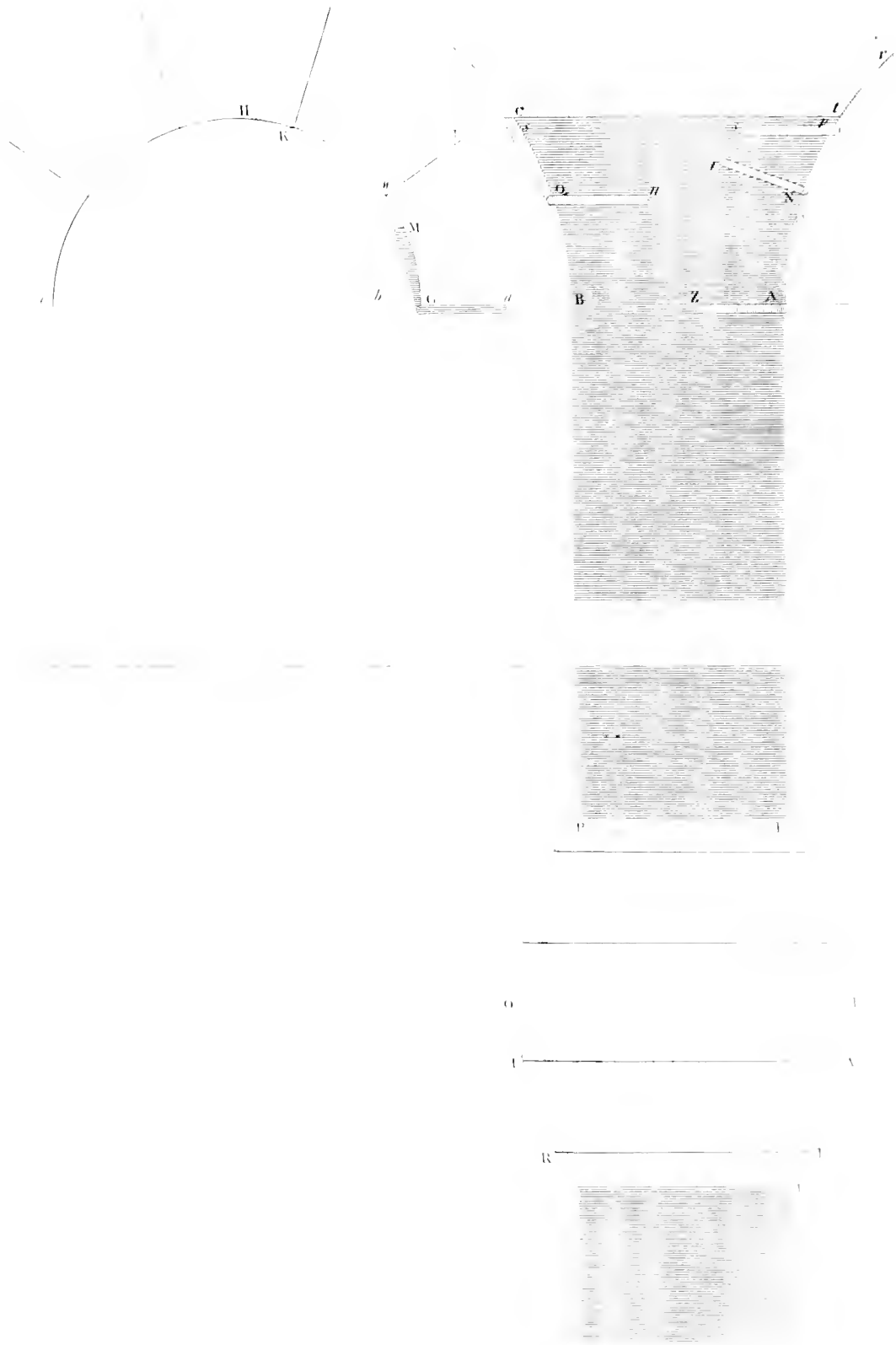
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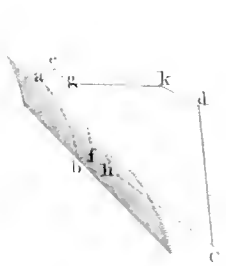

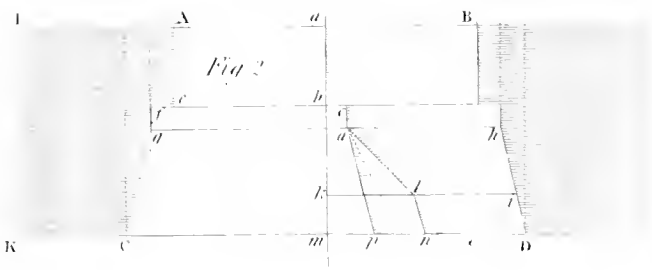

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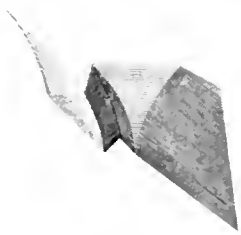

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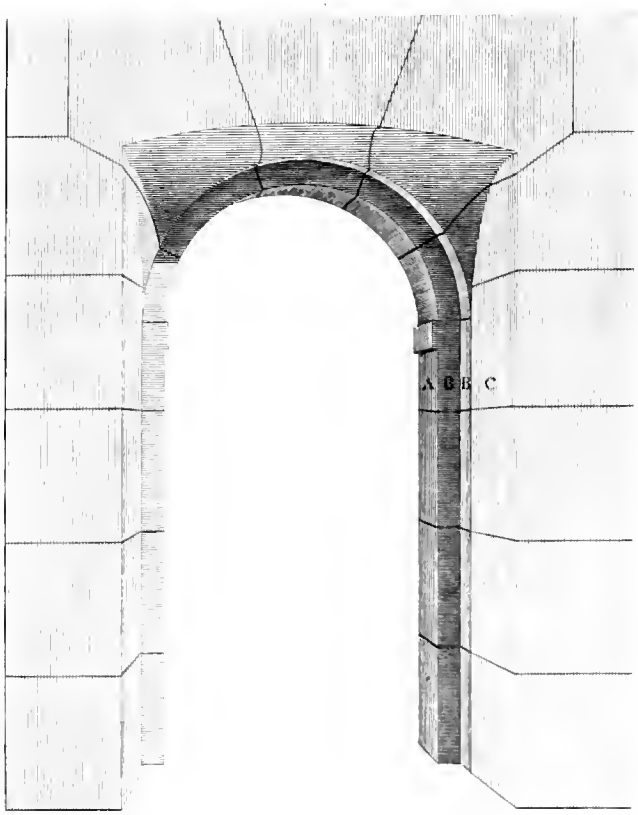

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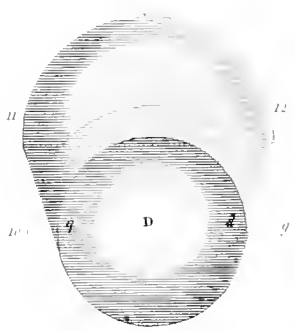

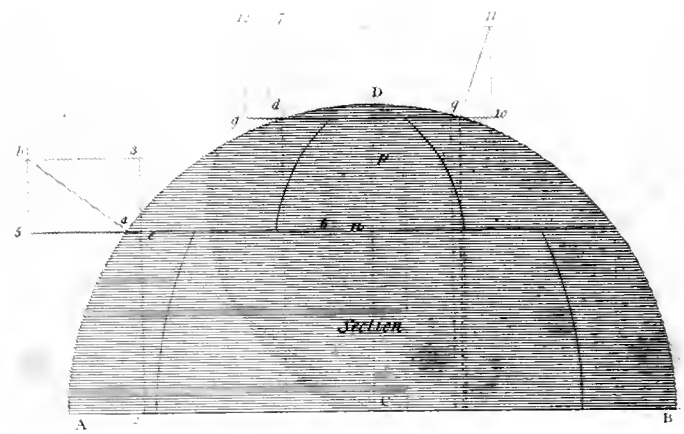

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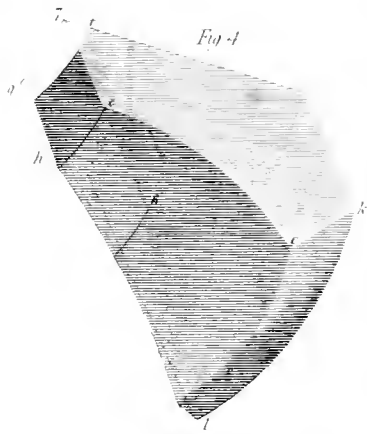

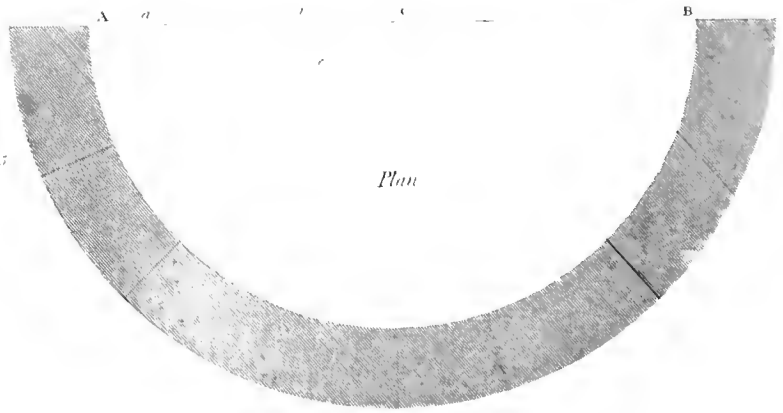

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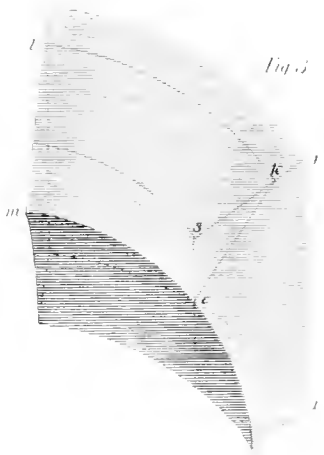

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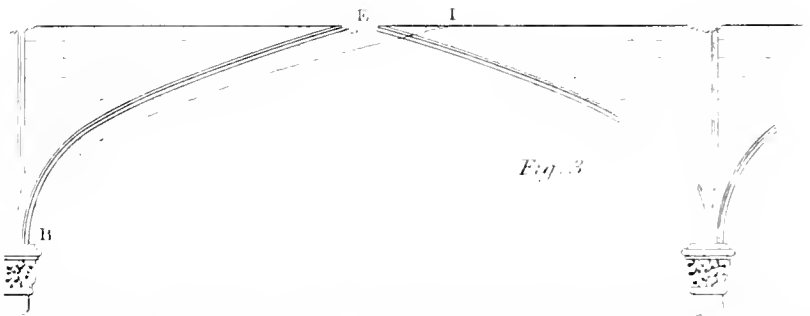

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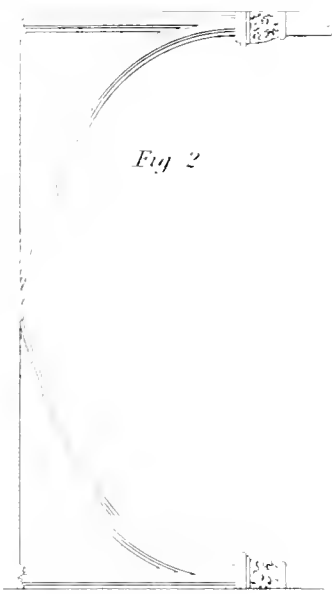

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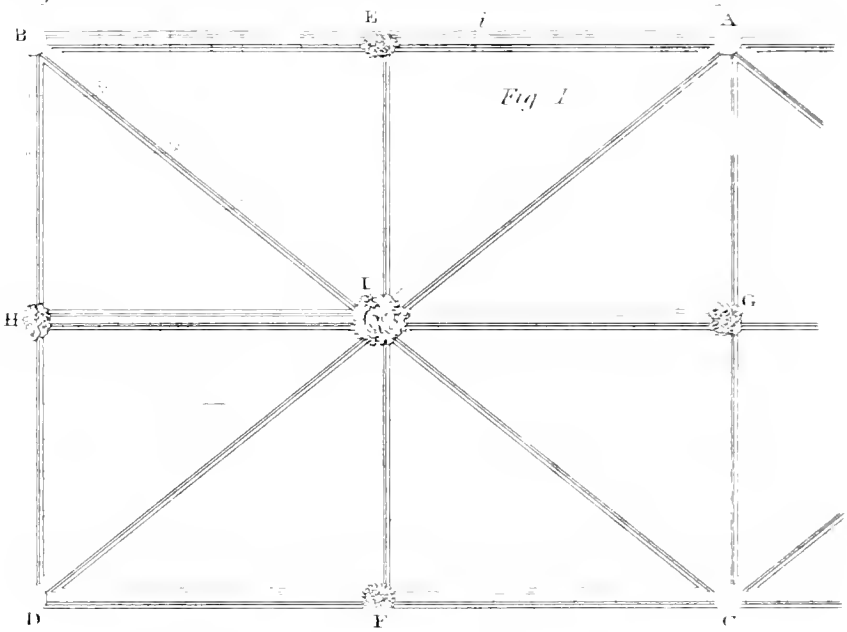

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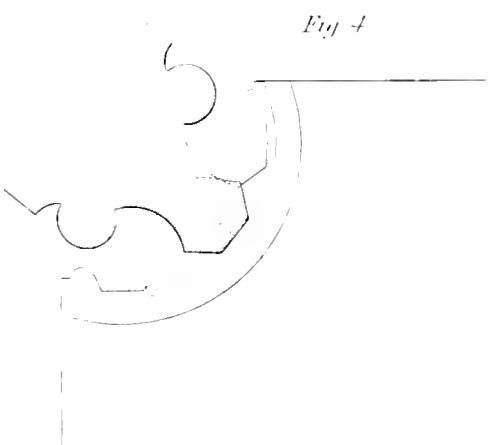

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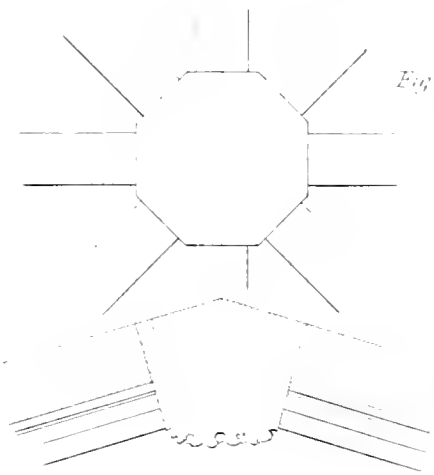

Fig 5

London Published by The Vitruvian Press, Pall Mall

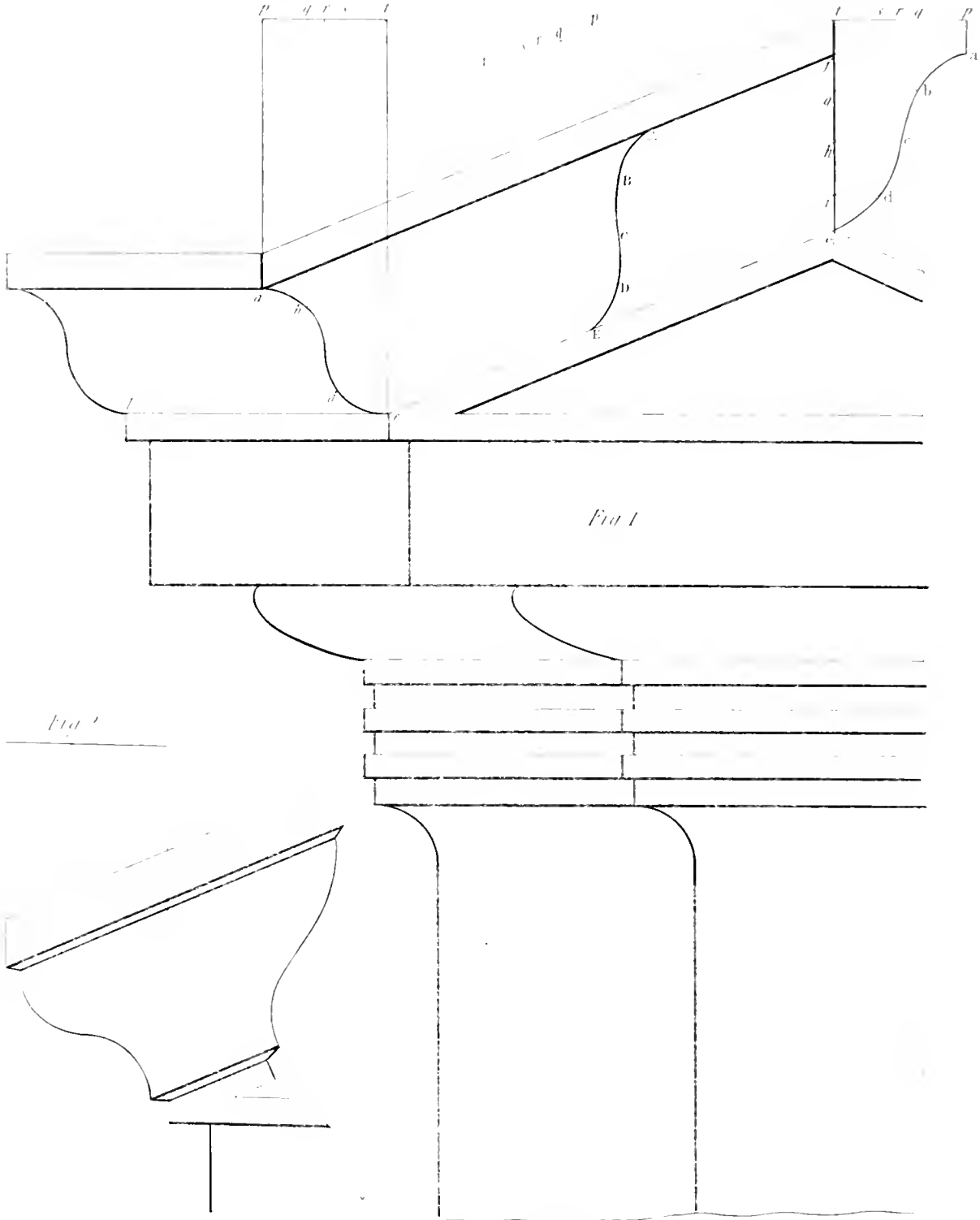
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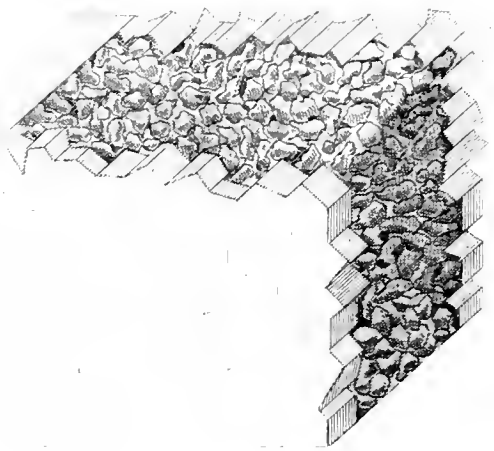
Fig 1
Fig 2

Fig. 1



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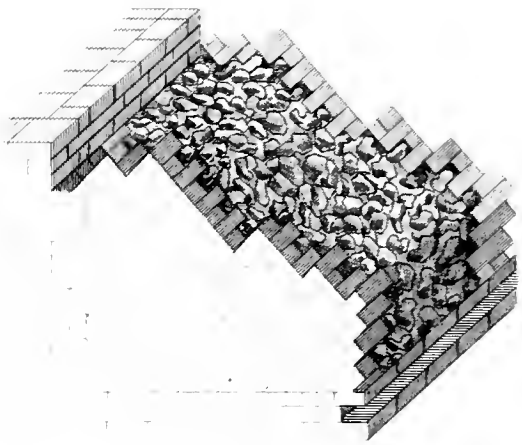

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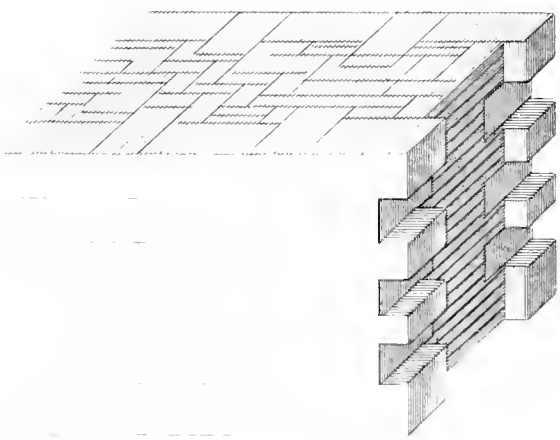

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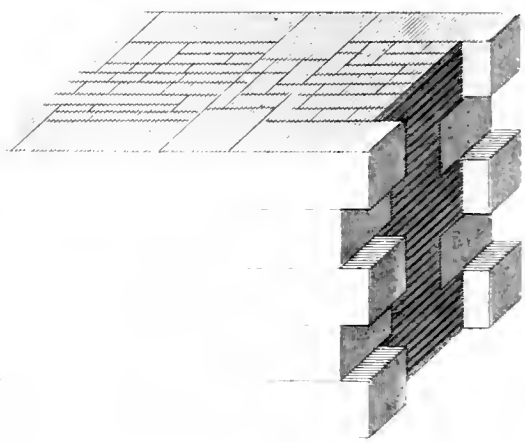

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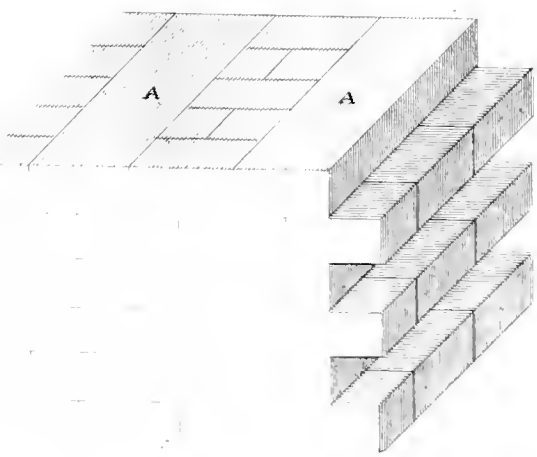

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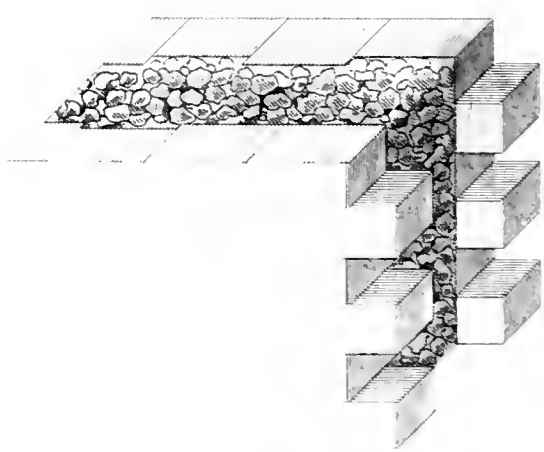

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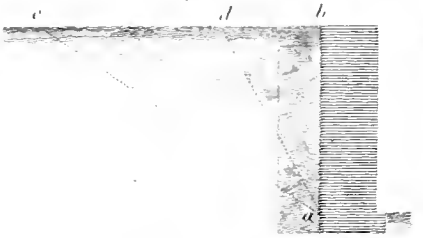

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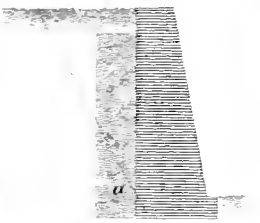

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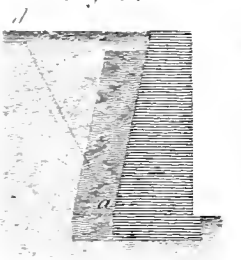

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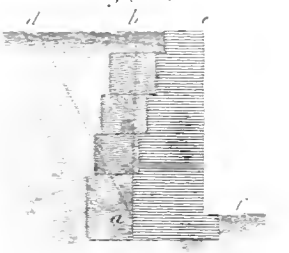

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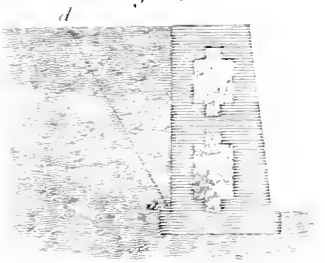

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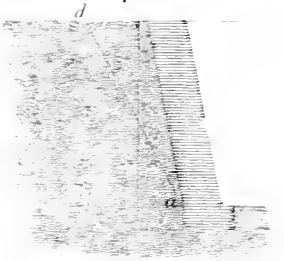

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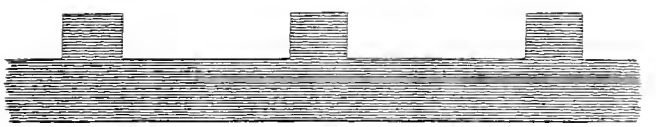

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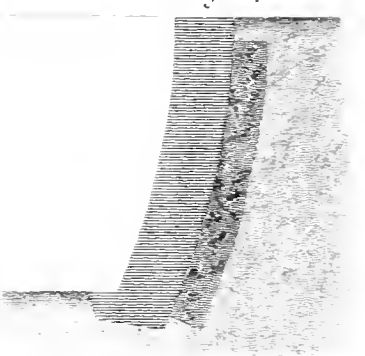

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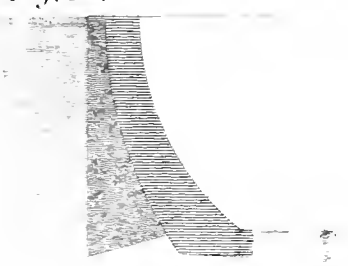

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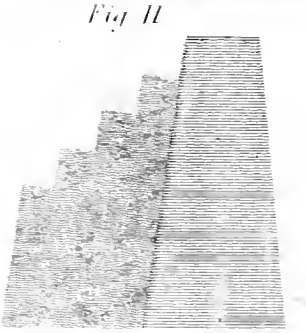
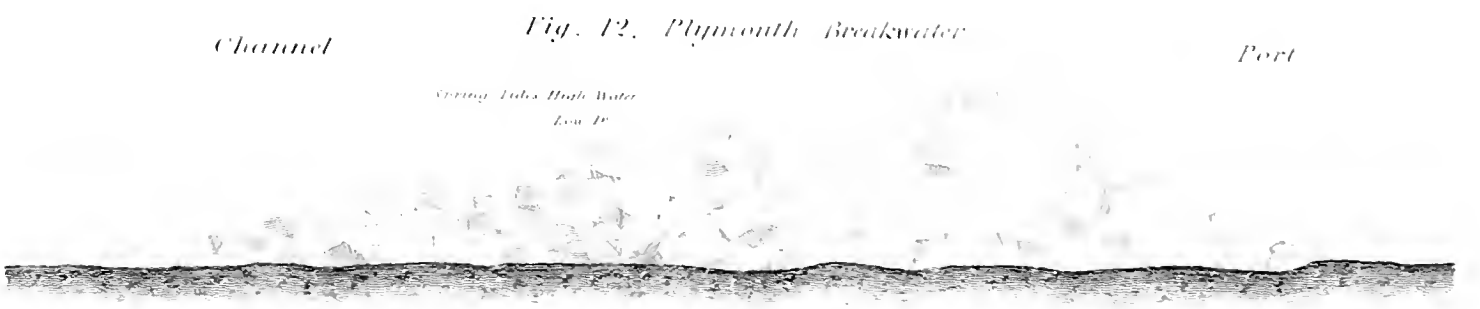


Fig. 12. Plymouth Breakwater



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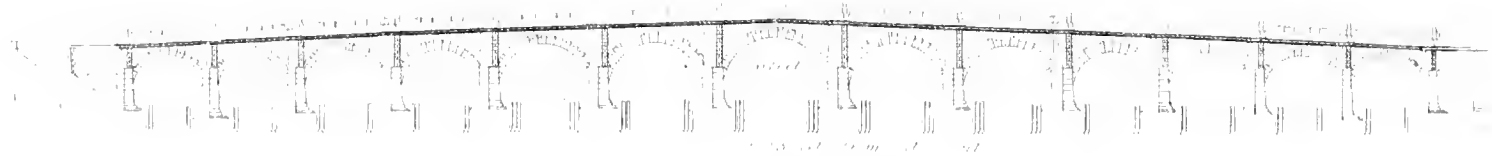
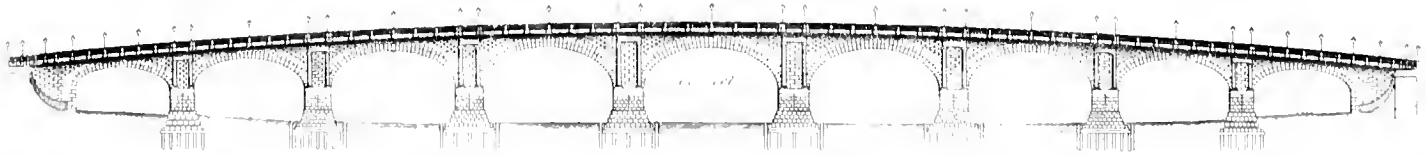
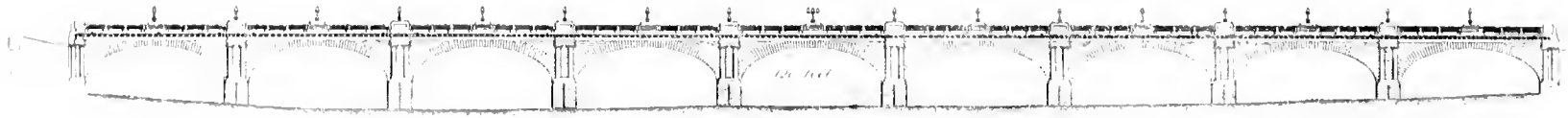
WESTMINSTER BRIDGE

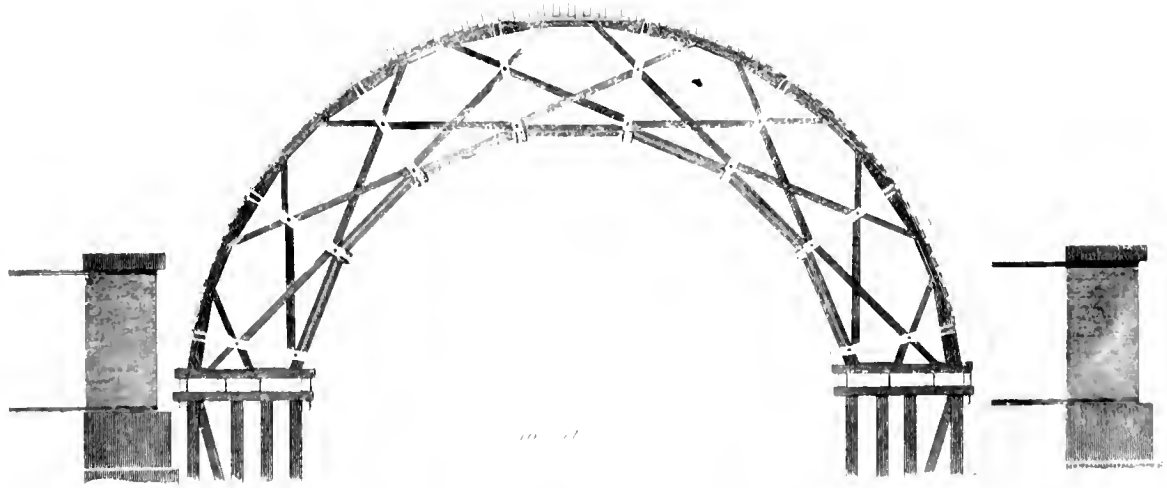


BLACKFRIARS BRIDGE

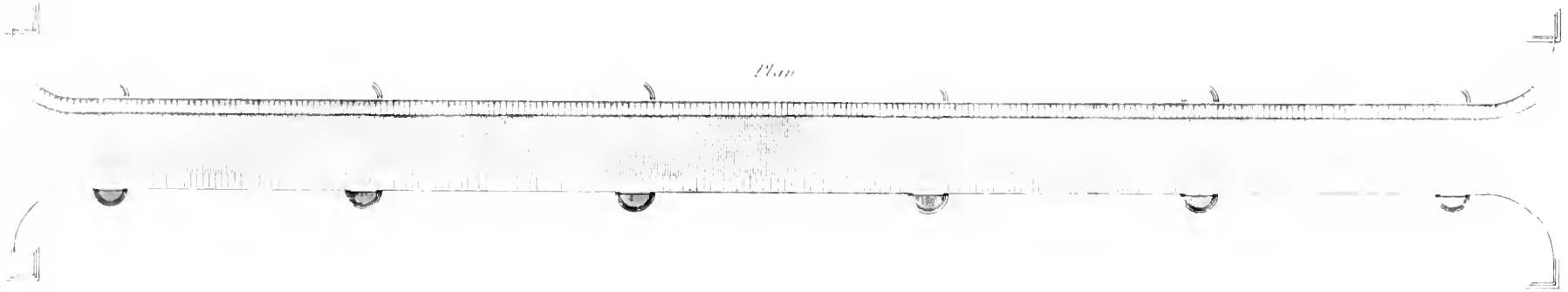


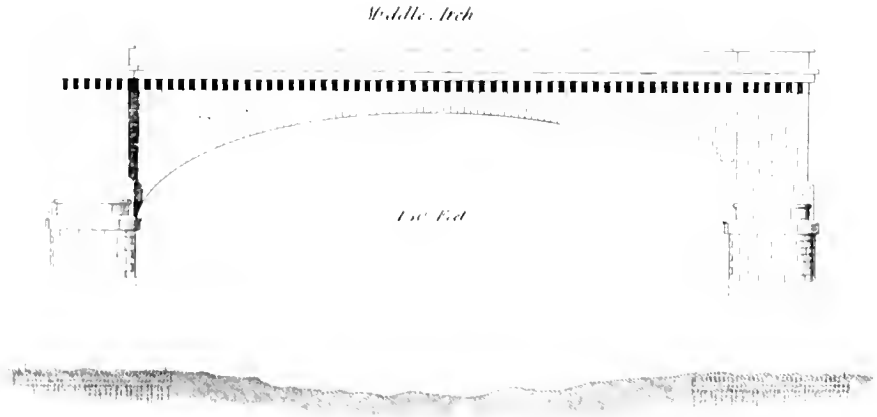
WATERLOO BRIDGE

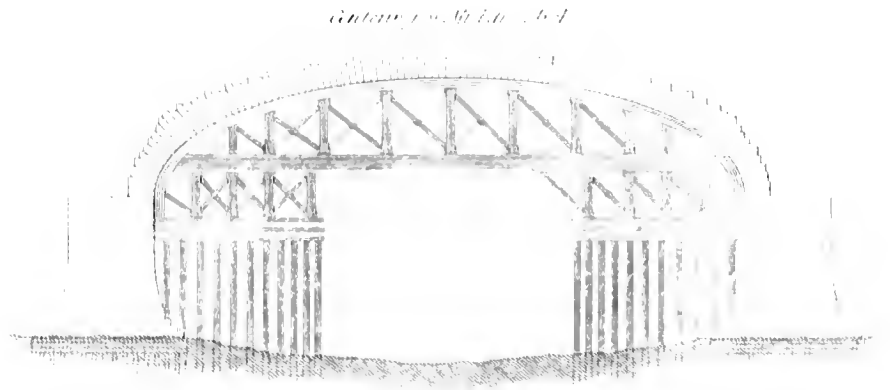


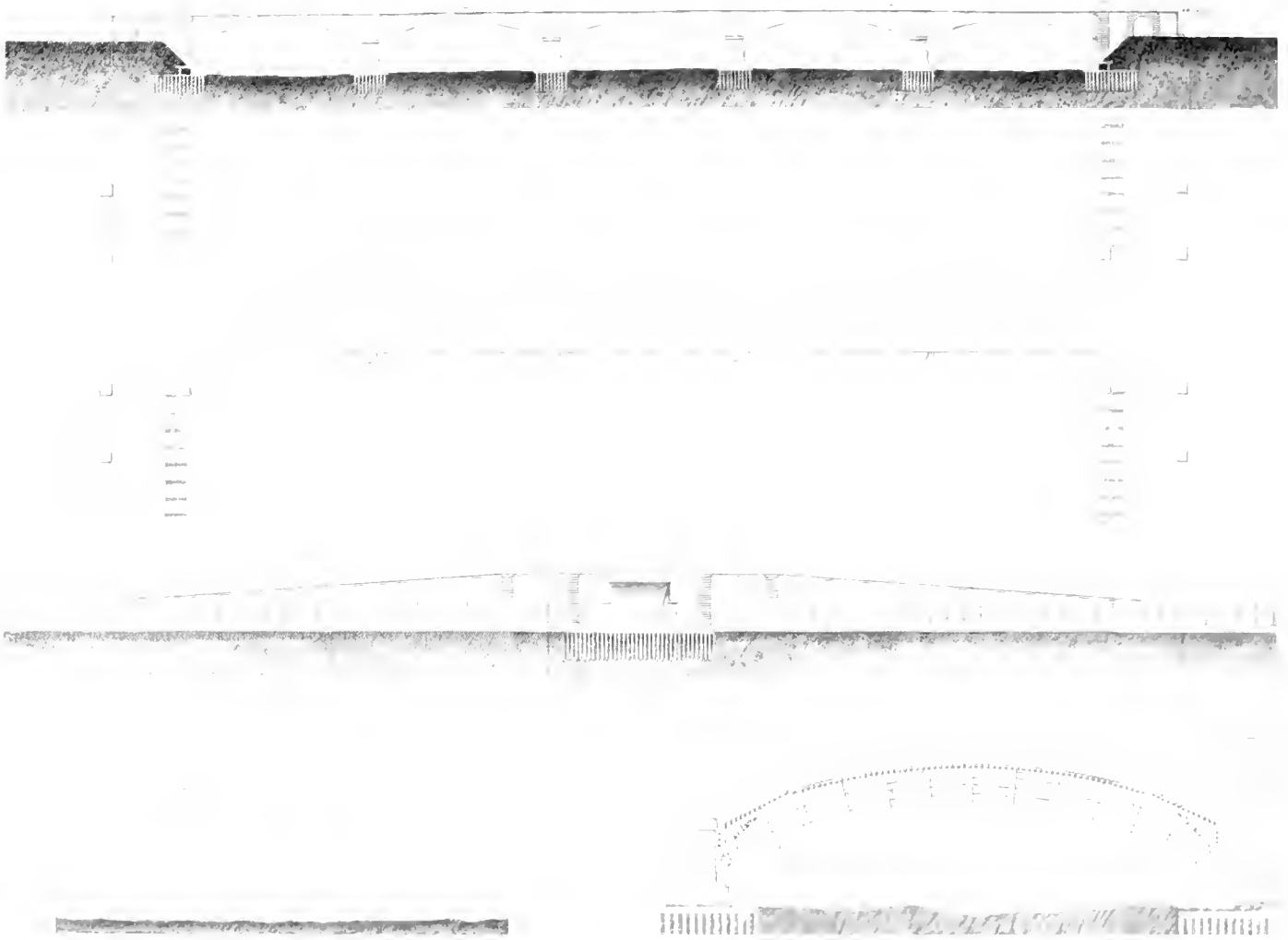


The new London Bridge over the River Thames



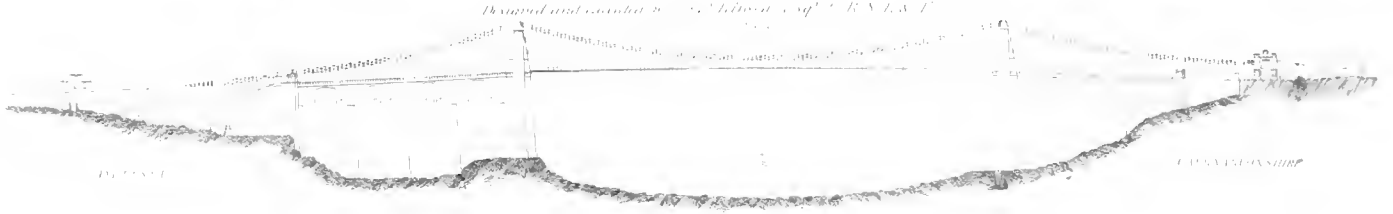


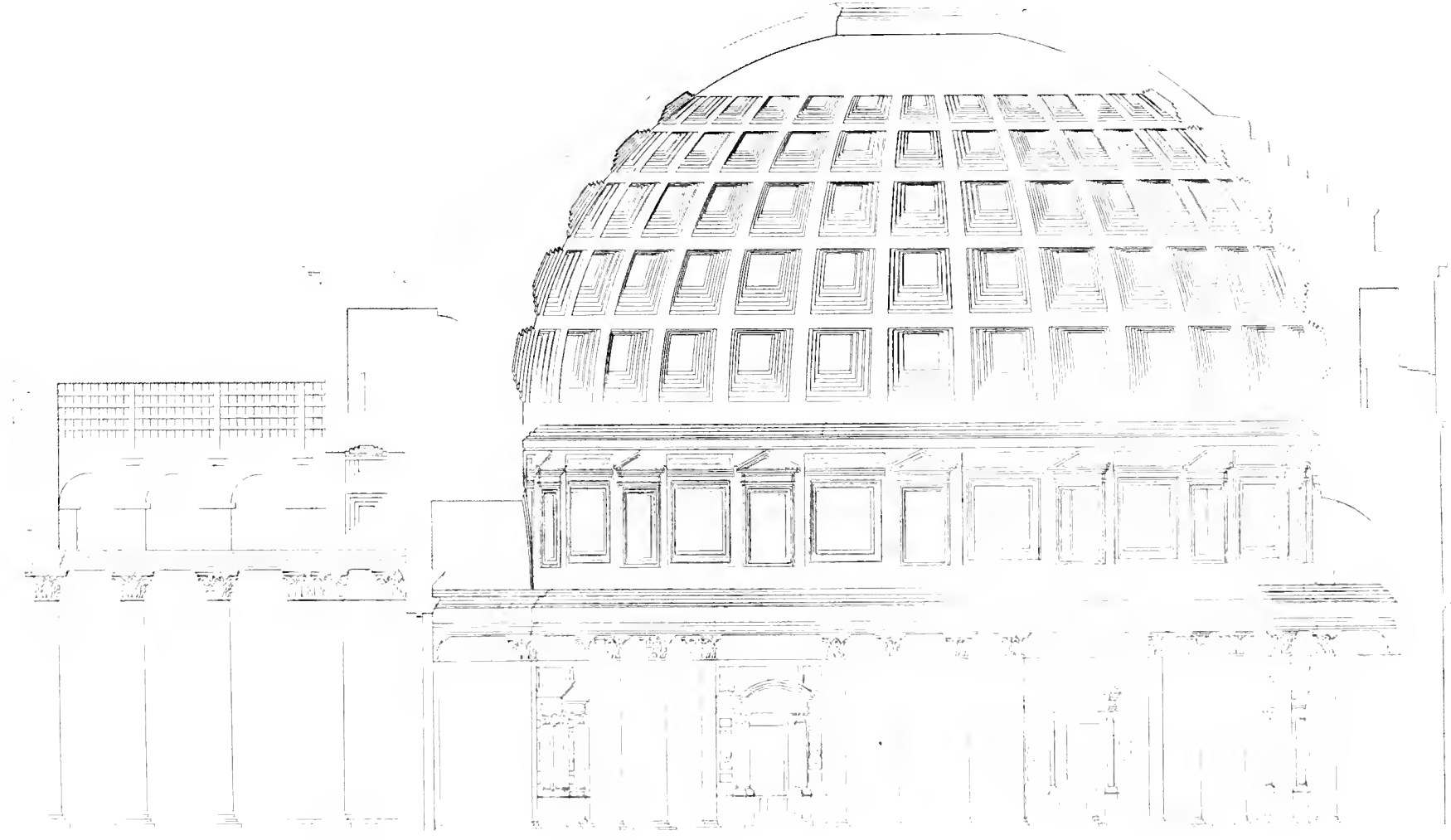




BRIDGE ACROSS THE SEVERN NEAR GLOUCESTER.

Designed and executed by T. Telford, Esq.r F.R.S.L. & E.





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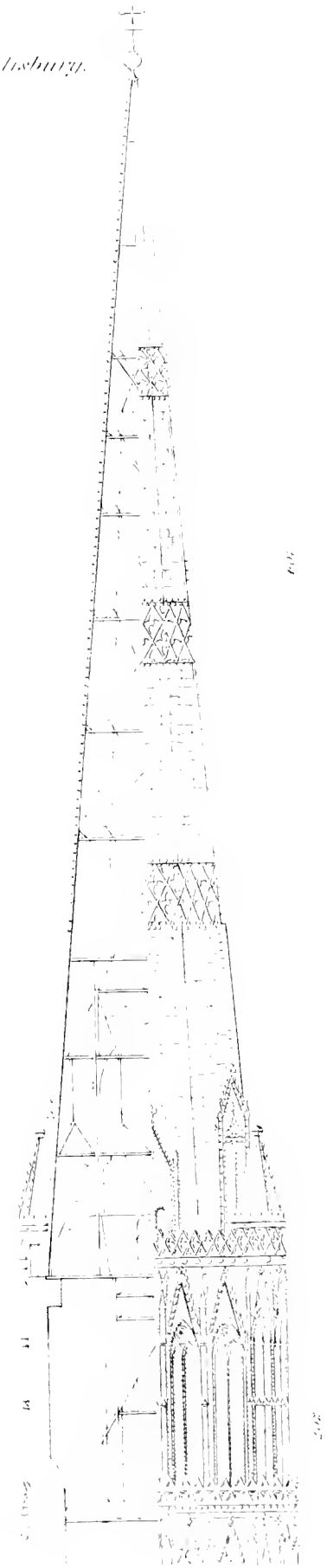

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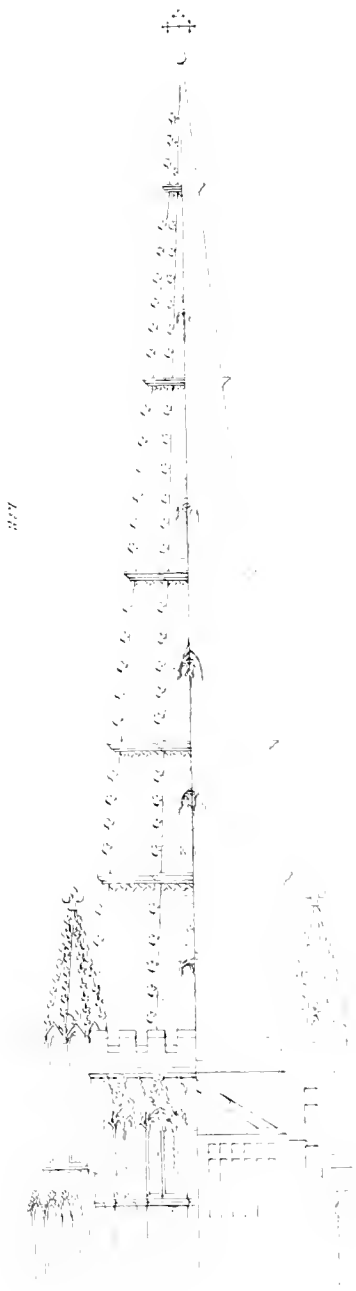

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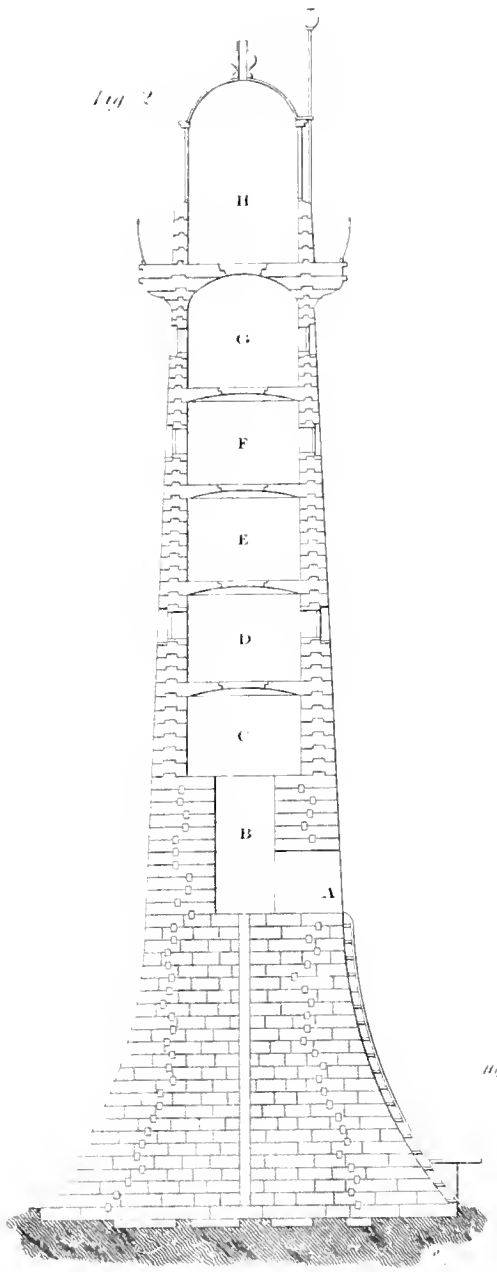
LIGHT HOUSE.

Fig. 2



High water Spring Tides.

Fig. 1

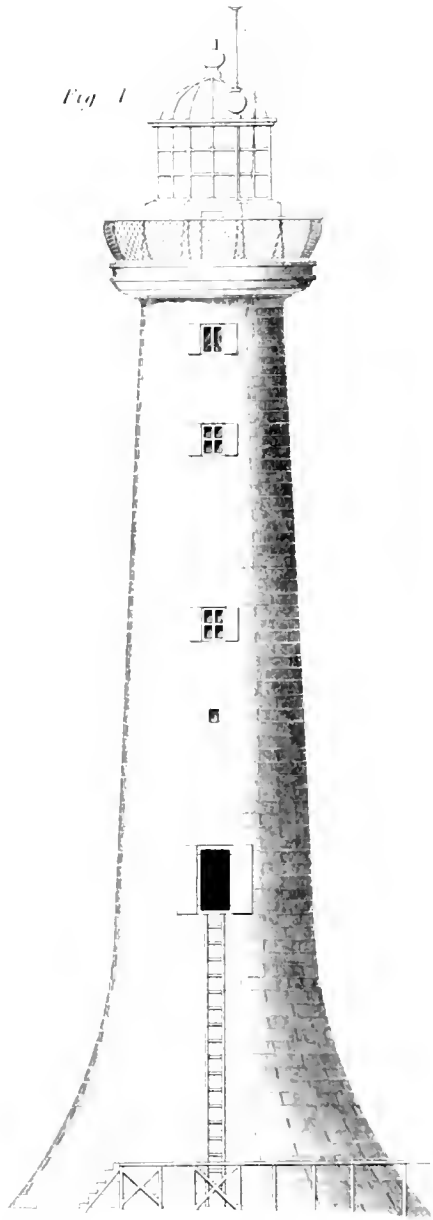


Fig. 3.

Fig. 4

Fig. 5.

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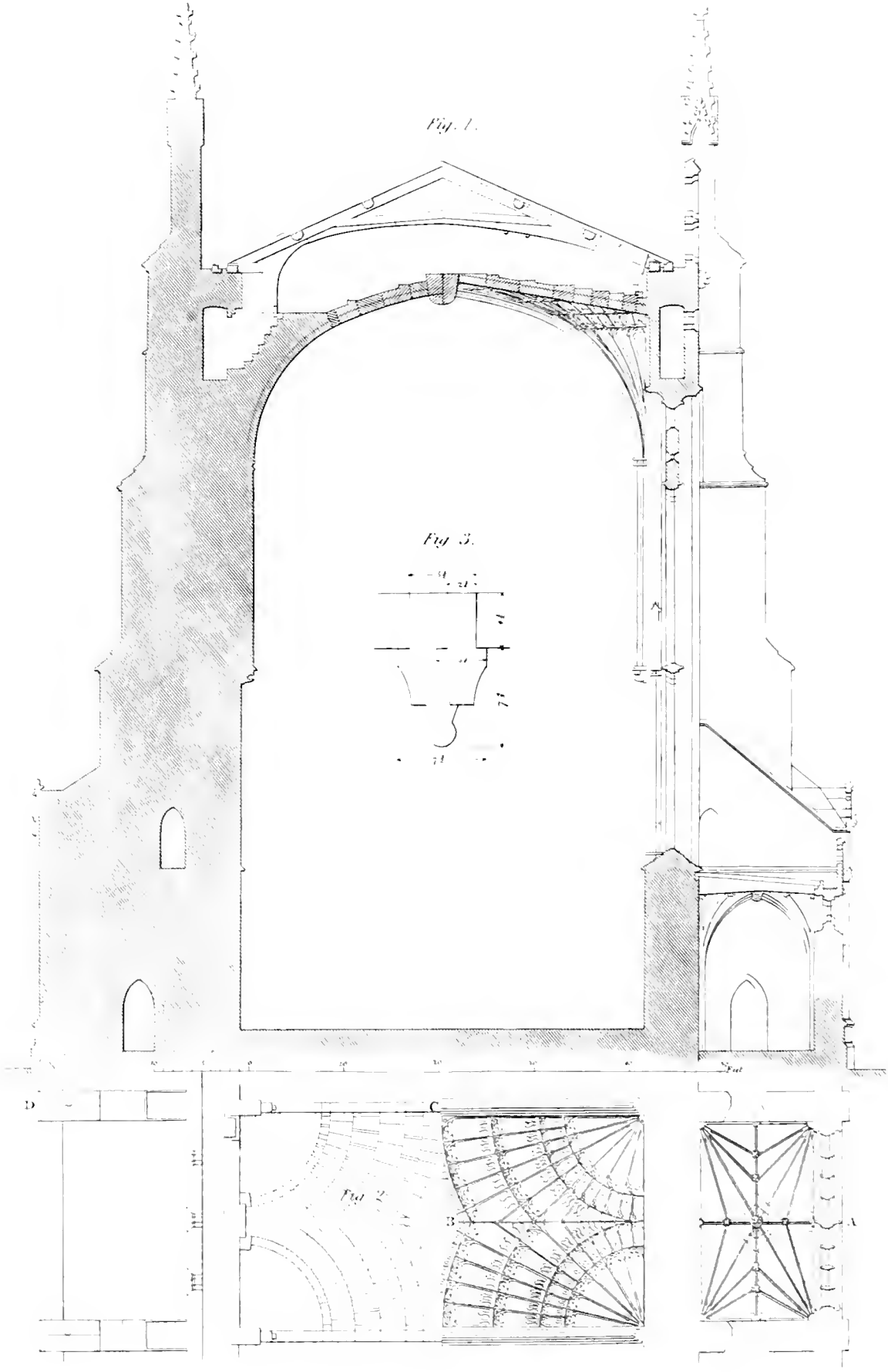
Groined Roof of Kings College Chapel Cambridge.



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MOULDINGS

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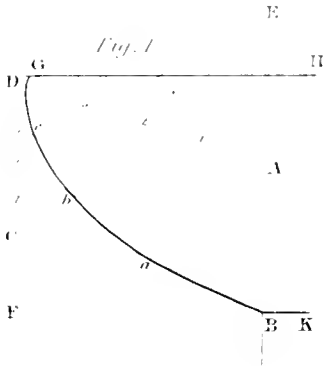

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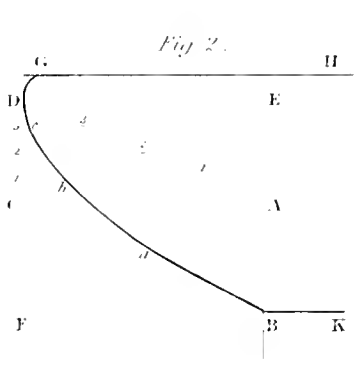

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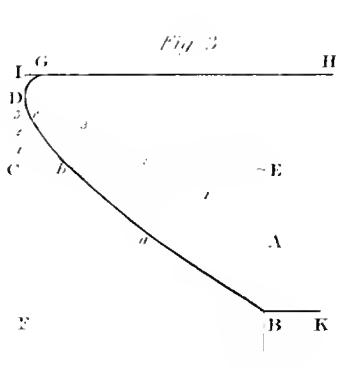

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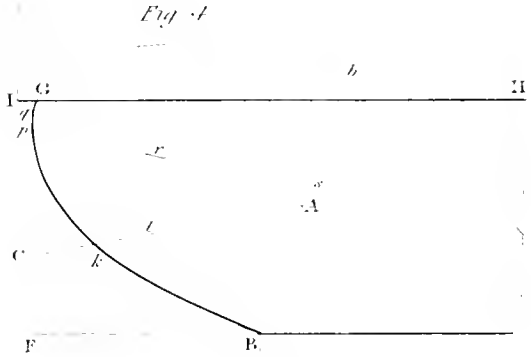

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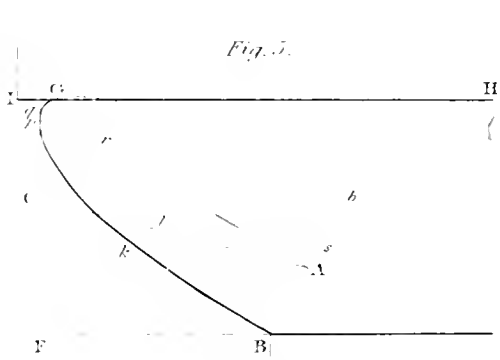

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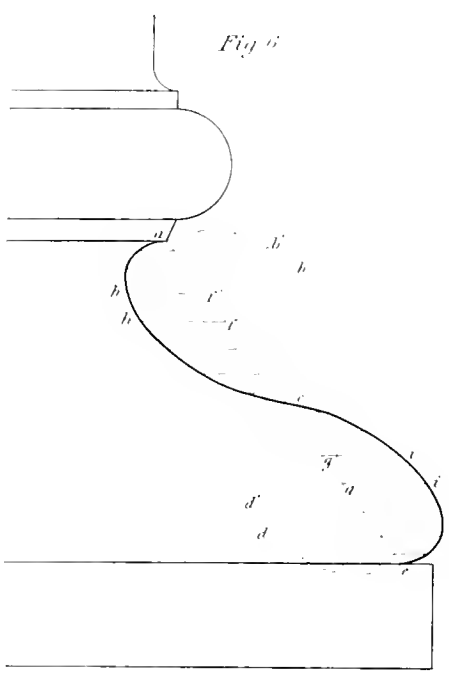

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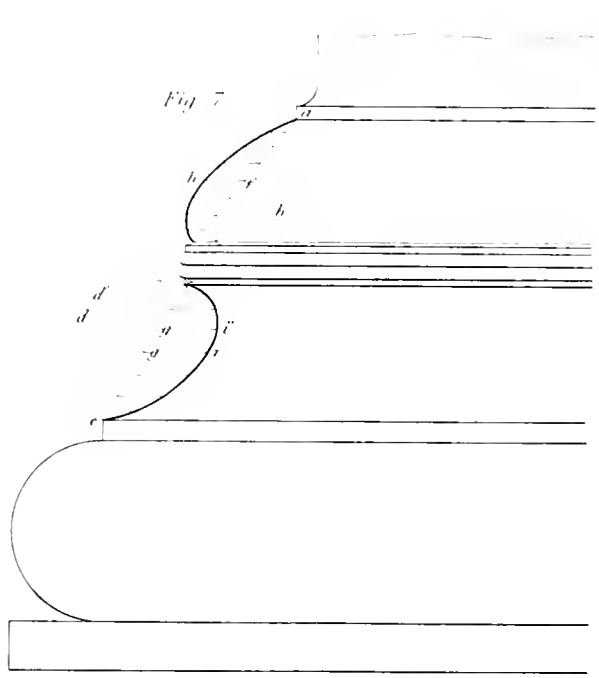

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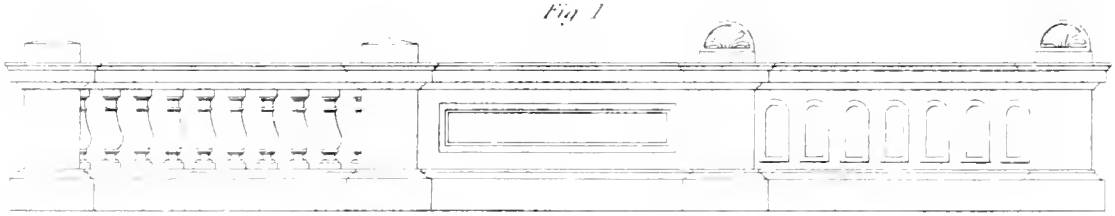

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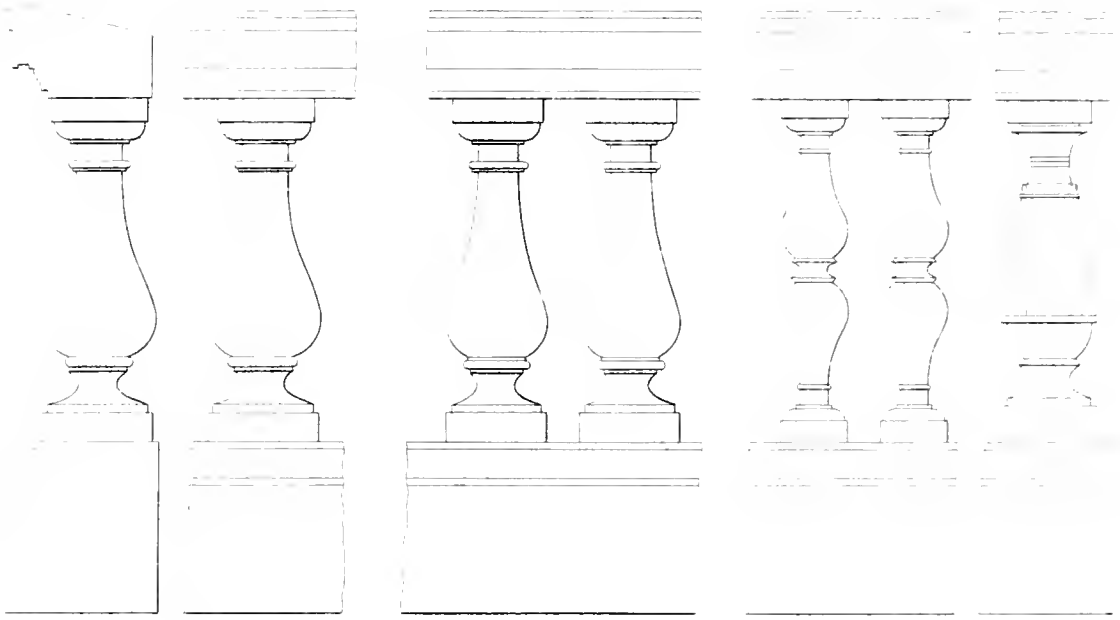

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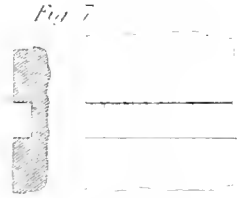

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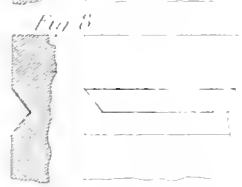

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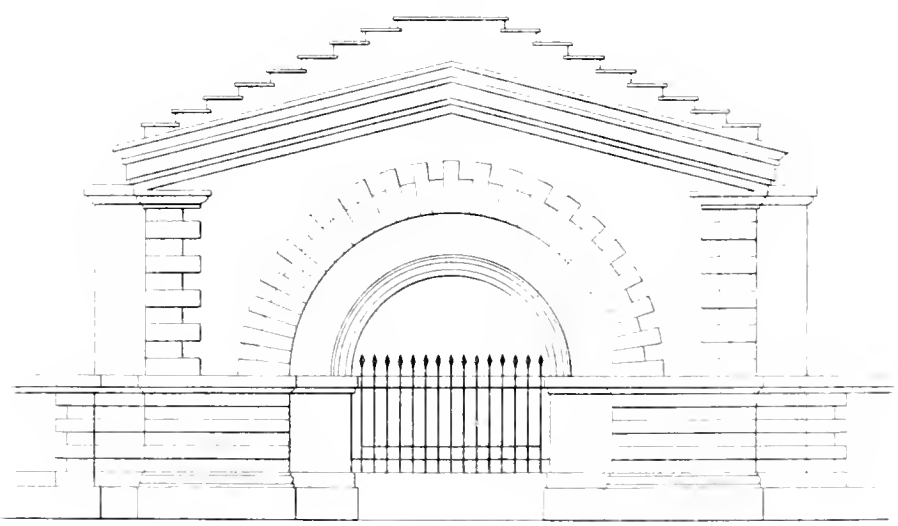

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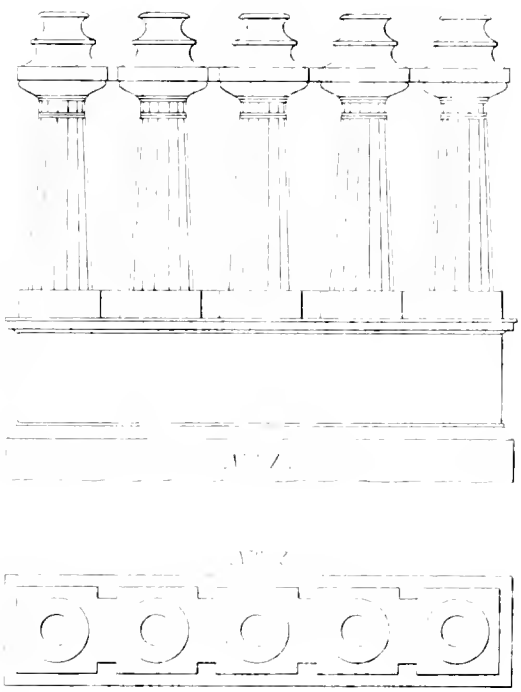

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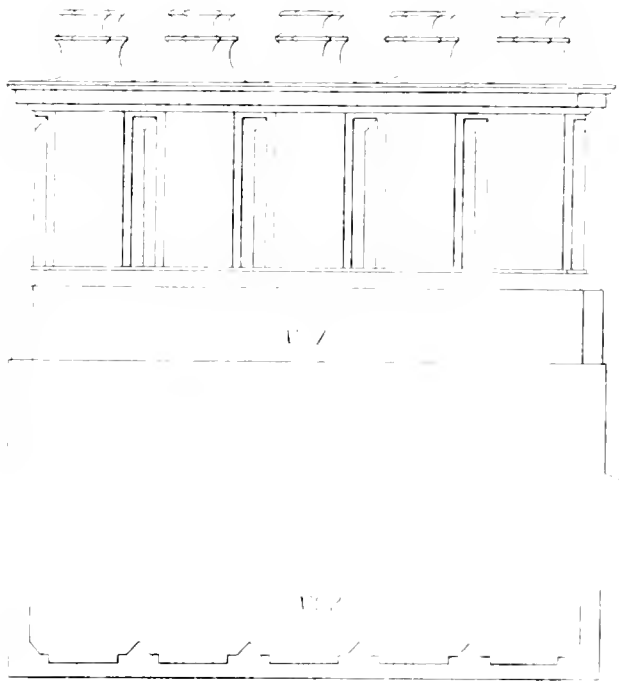

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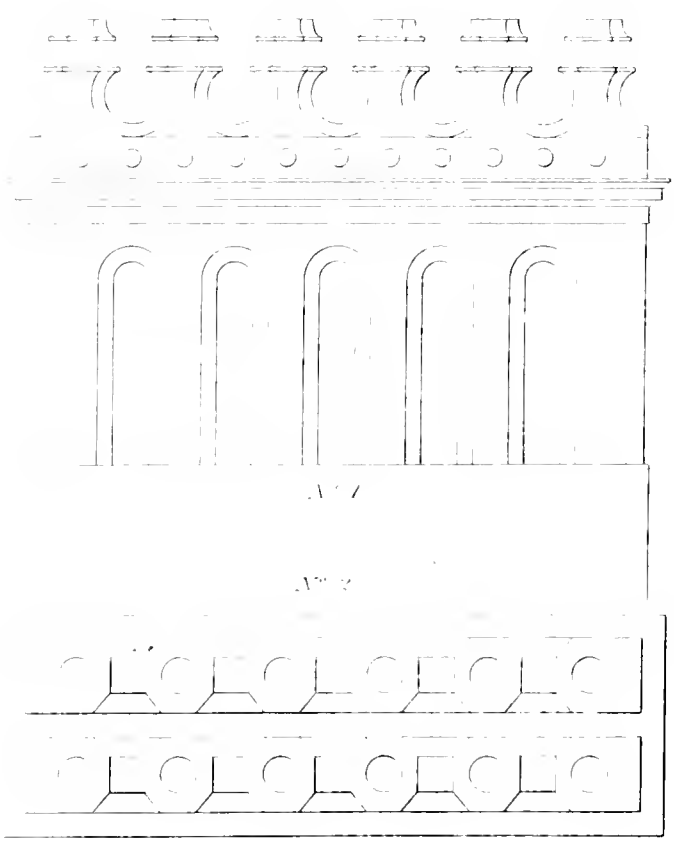

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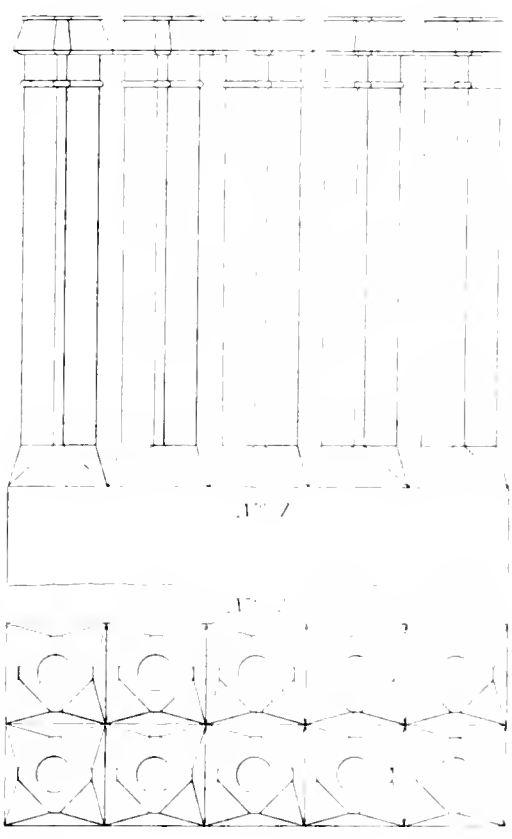


Fig. 1
Fig. 1
Fig. 2
Fig. 3
Fig. 3
Fig. 4

ORNAMENTAL MASONRY.

WINDOWS

Fig 1

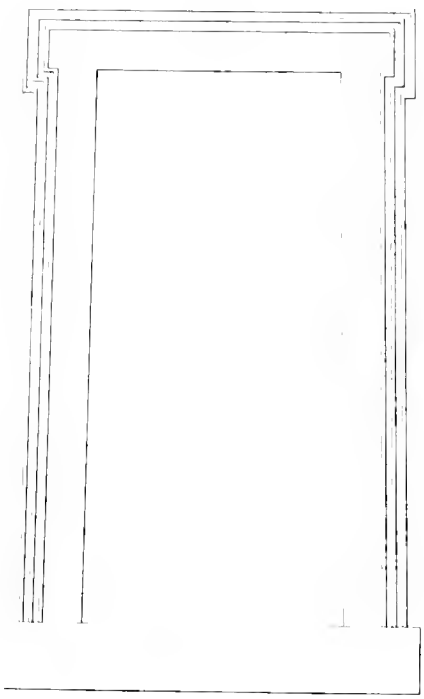
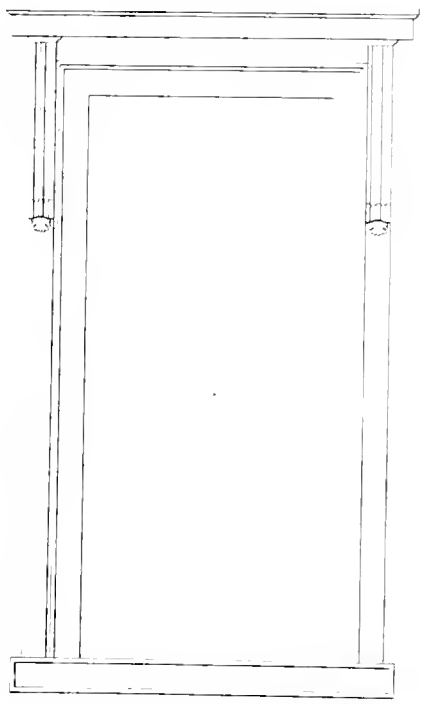


Fig 3

Fig 2



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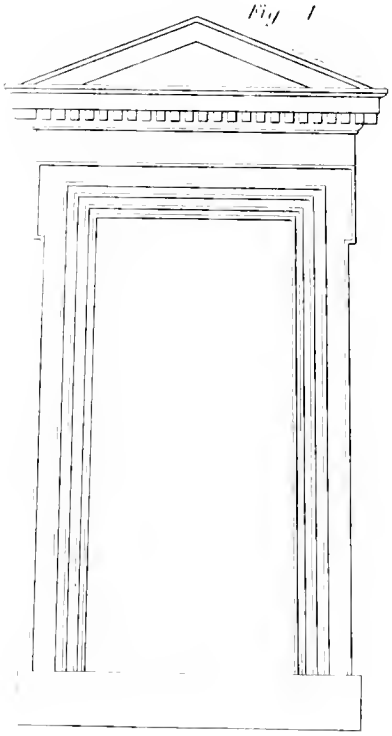

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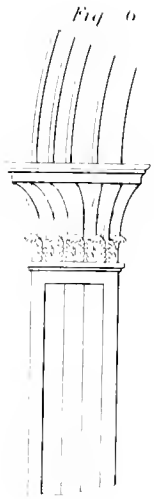

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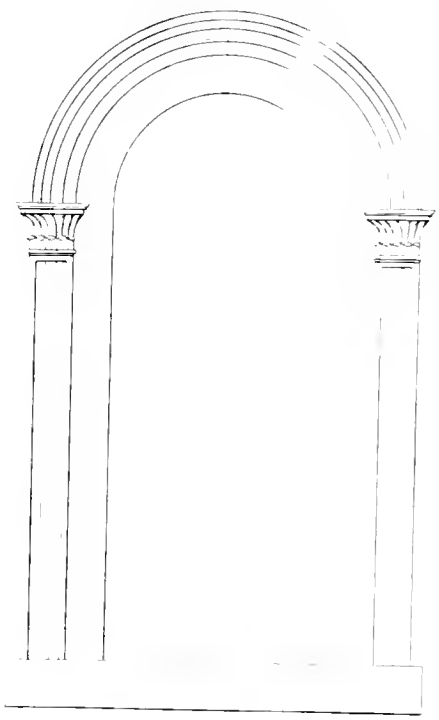

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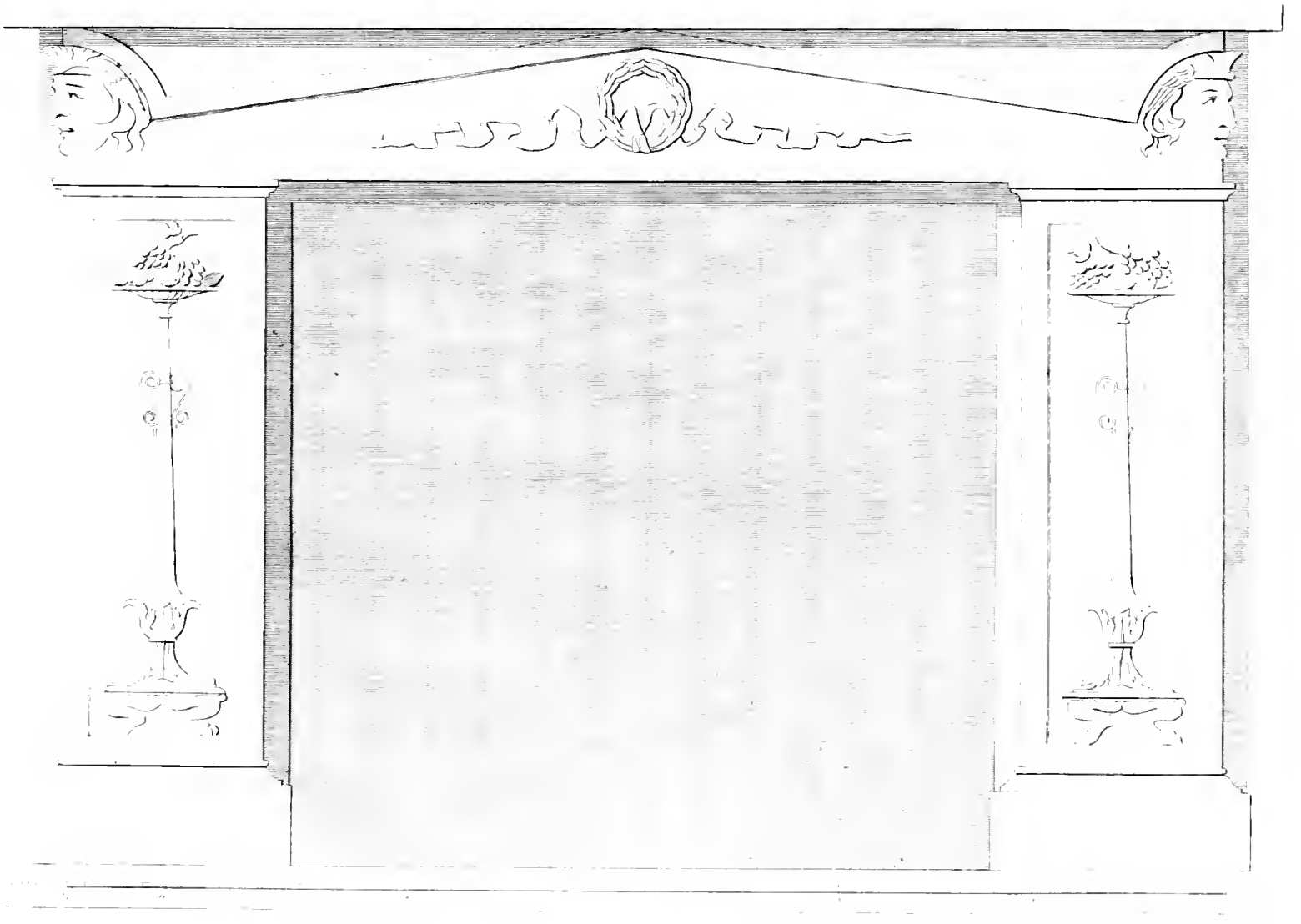
ORNAMENTAL MASONRY.

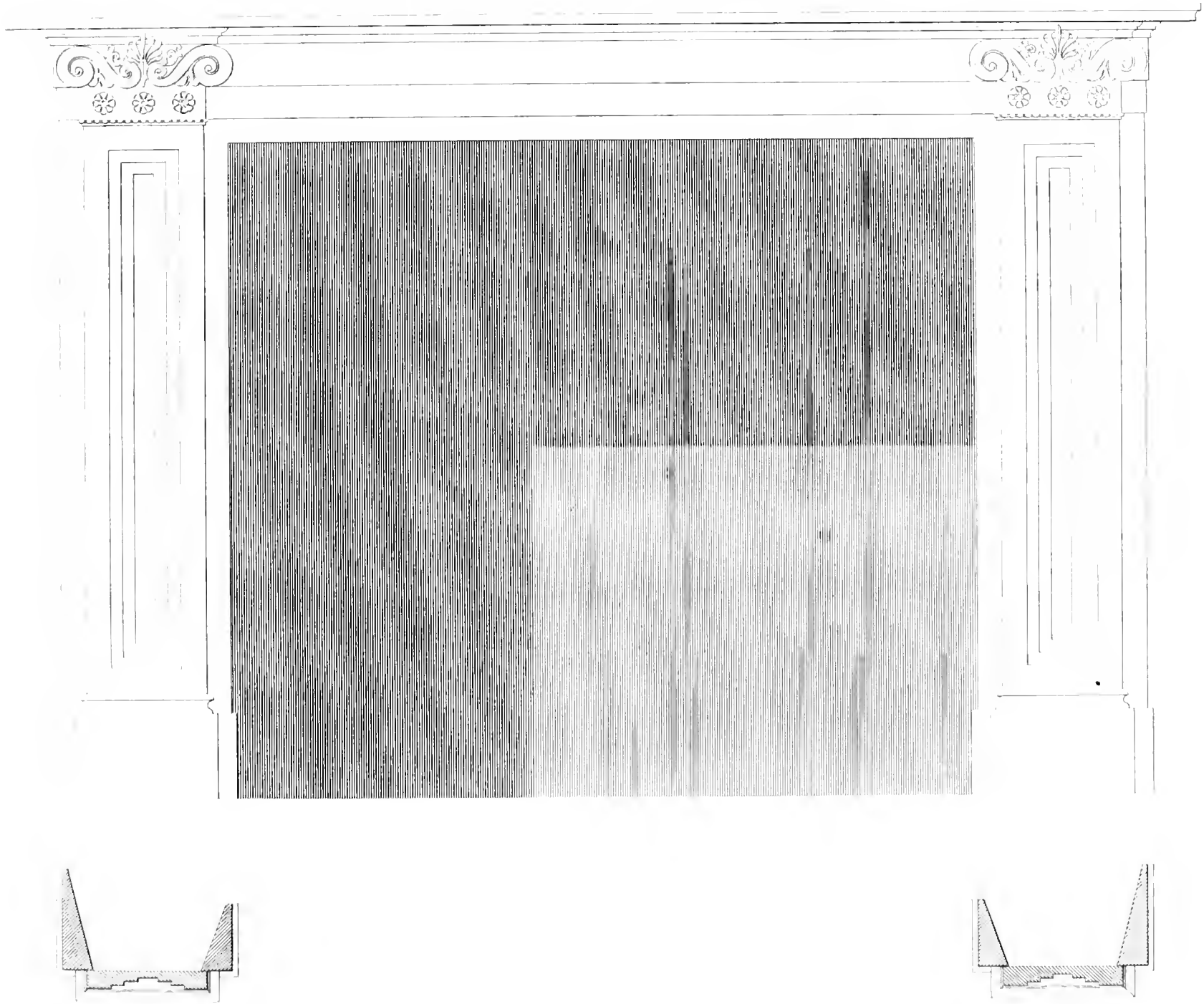
DESIGN FOR A GRECIAN CHIMNEY PIECE,

EXECUTED BY PETER TURNERELLI ESQ SCULPTOR TO HIS LATE MAJESTY GEO III



ORNAMENTAL MASONRY.

CHIMNEY PIECE IN THE GRECIAN STYLE



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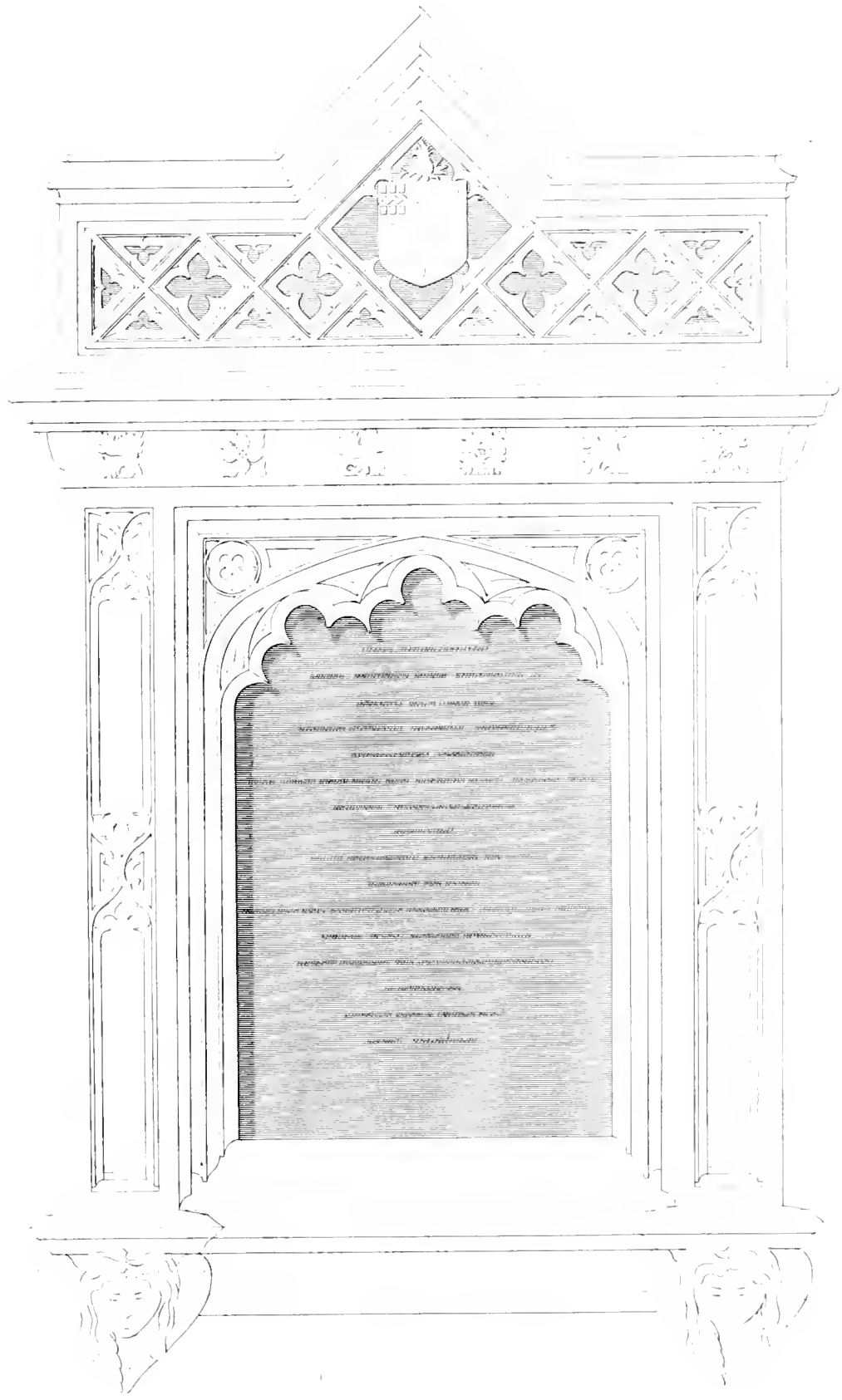
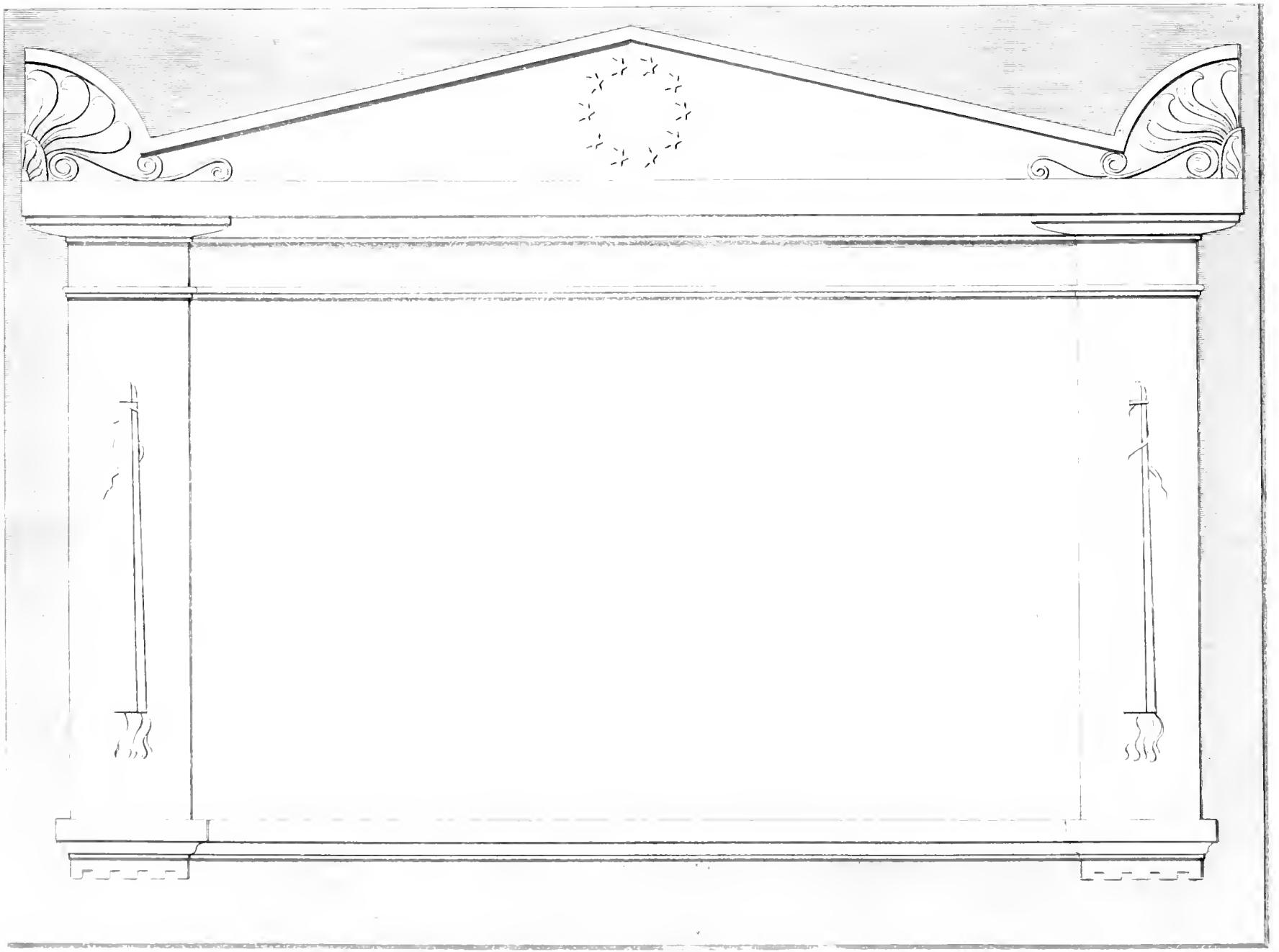
GOTHIC MEDIAL MONUMENT IN HARROW CHURCH



Etched by C. H. Smith

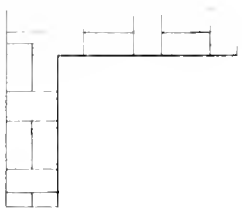
ORNAMENTAL MASONRY.
GRECIAN MONUMENT,
IN SAINT BENET'S GRACECHURCH STREET, EXECUTED BY R. WESTMACOTT ESQ. R.A.



BRICKLAYING.

Fig. 1.

Fig. 2



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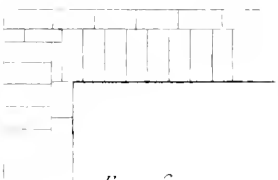

Fig. 4.

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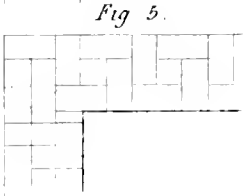

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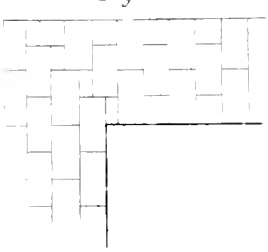

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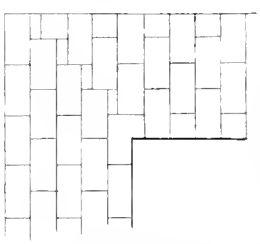

Fig. 8

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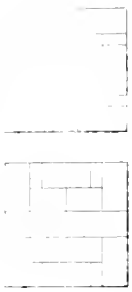

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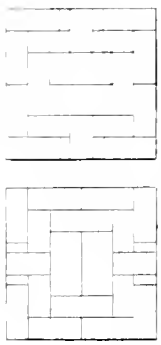

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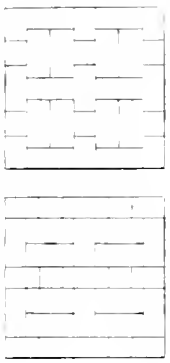

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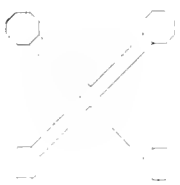

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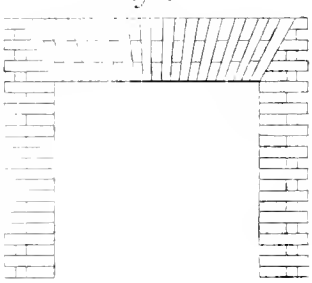

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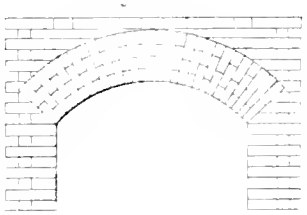

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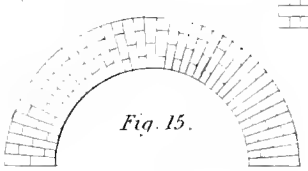

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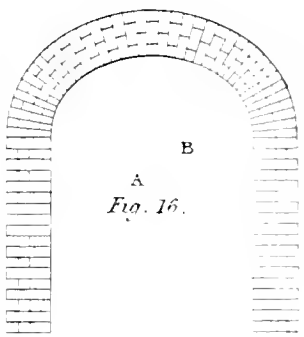

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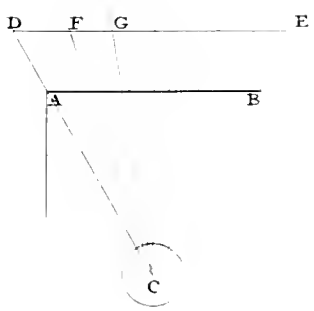
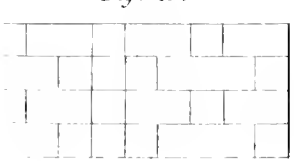


Fig. 18.

Fig. 19.

Fig. 20.



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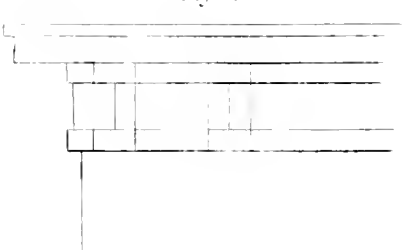

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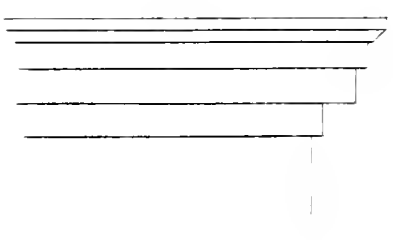
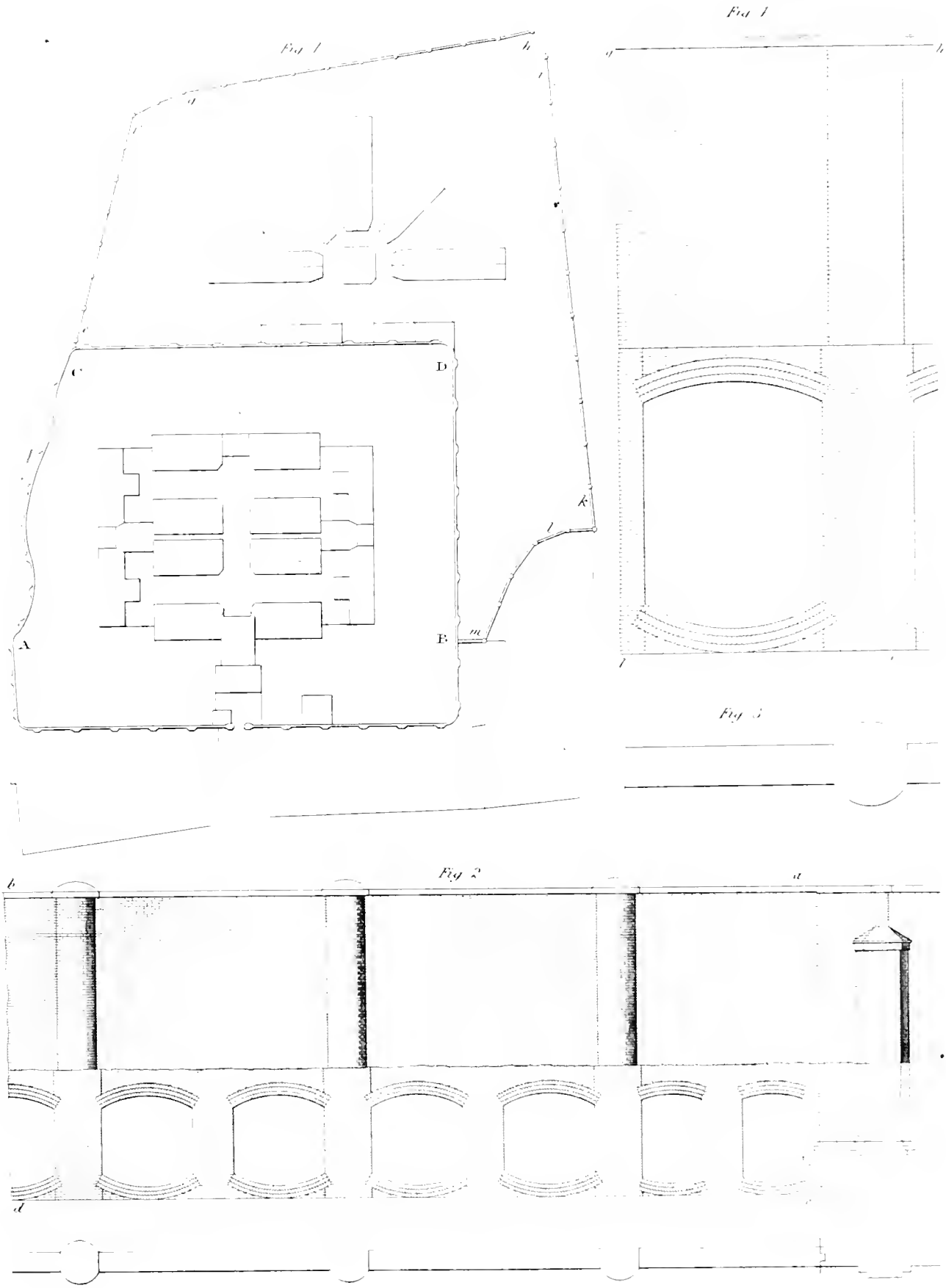


Engraved by W. Jones

London Published by Thos. Kelly 141 Fleet Street E.C. 1 January 1842

BRICKLAYING.

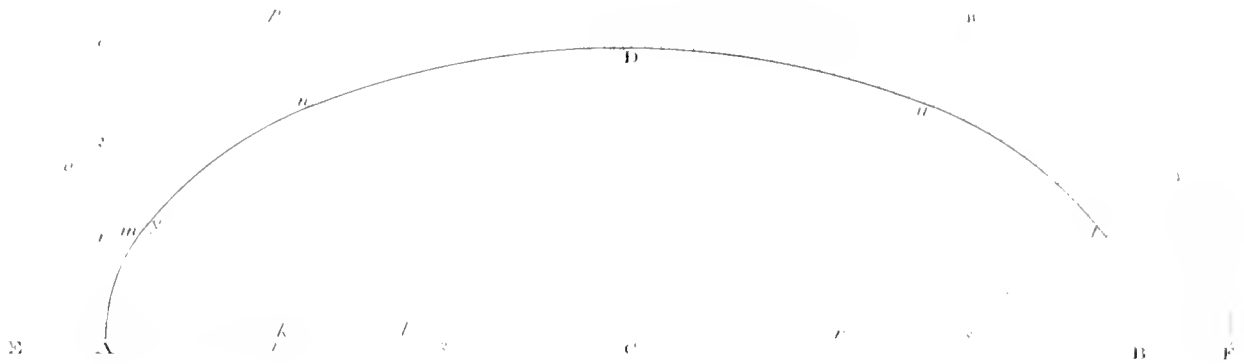
Wall at Old Bath Field's Prison

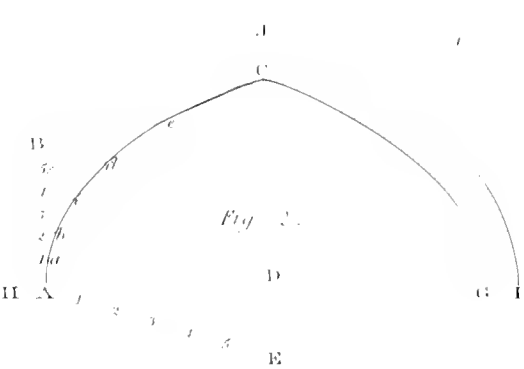


London Published by The Kelly 71 Paternoster Row May

Description of Arches

Fig. 1





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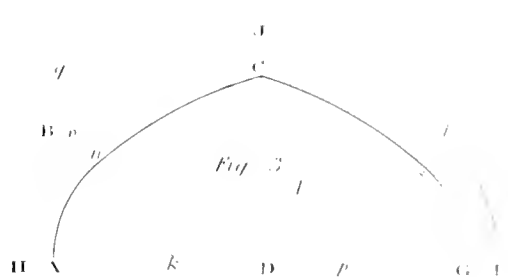

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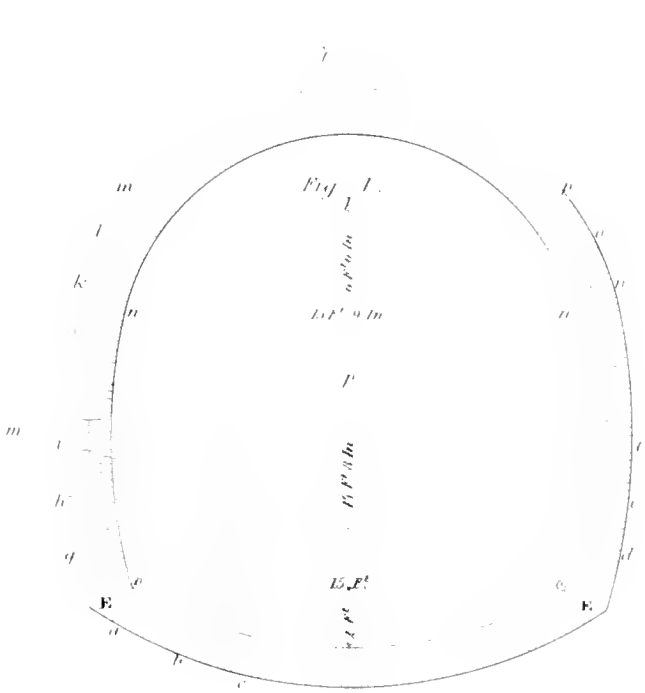

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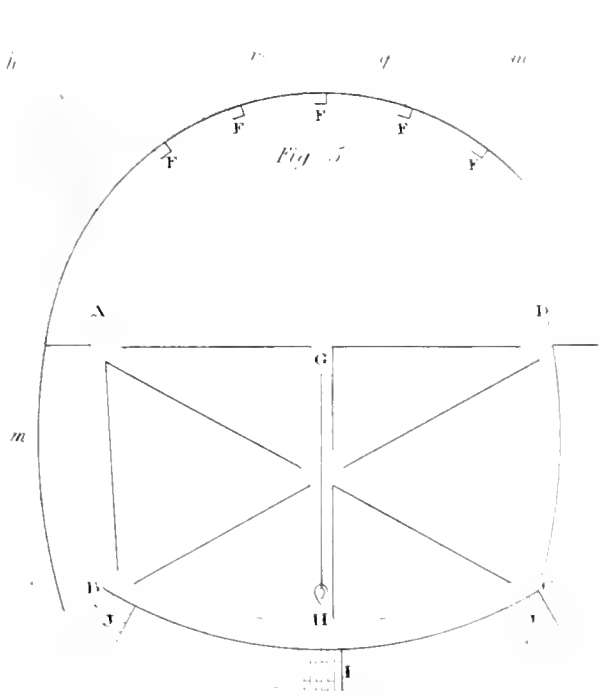


Fig. 5

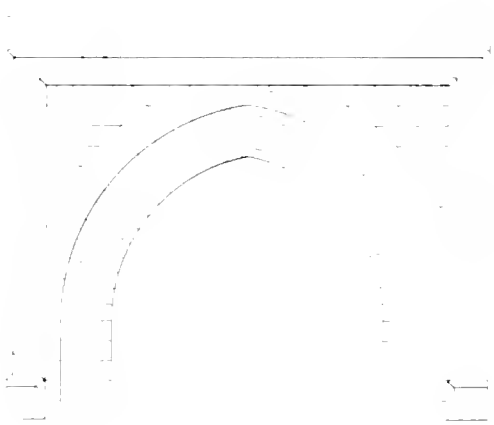
London, Published by Thos. Kelly, 17 Paternoster Row, May 1st 1830

BRICK ARCHES.

Window & Door; with Details in Tottenham New Church

Fig. 1

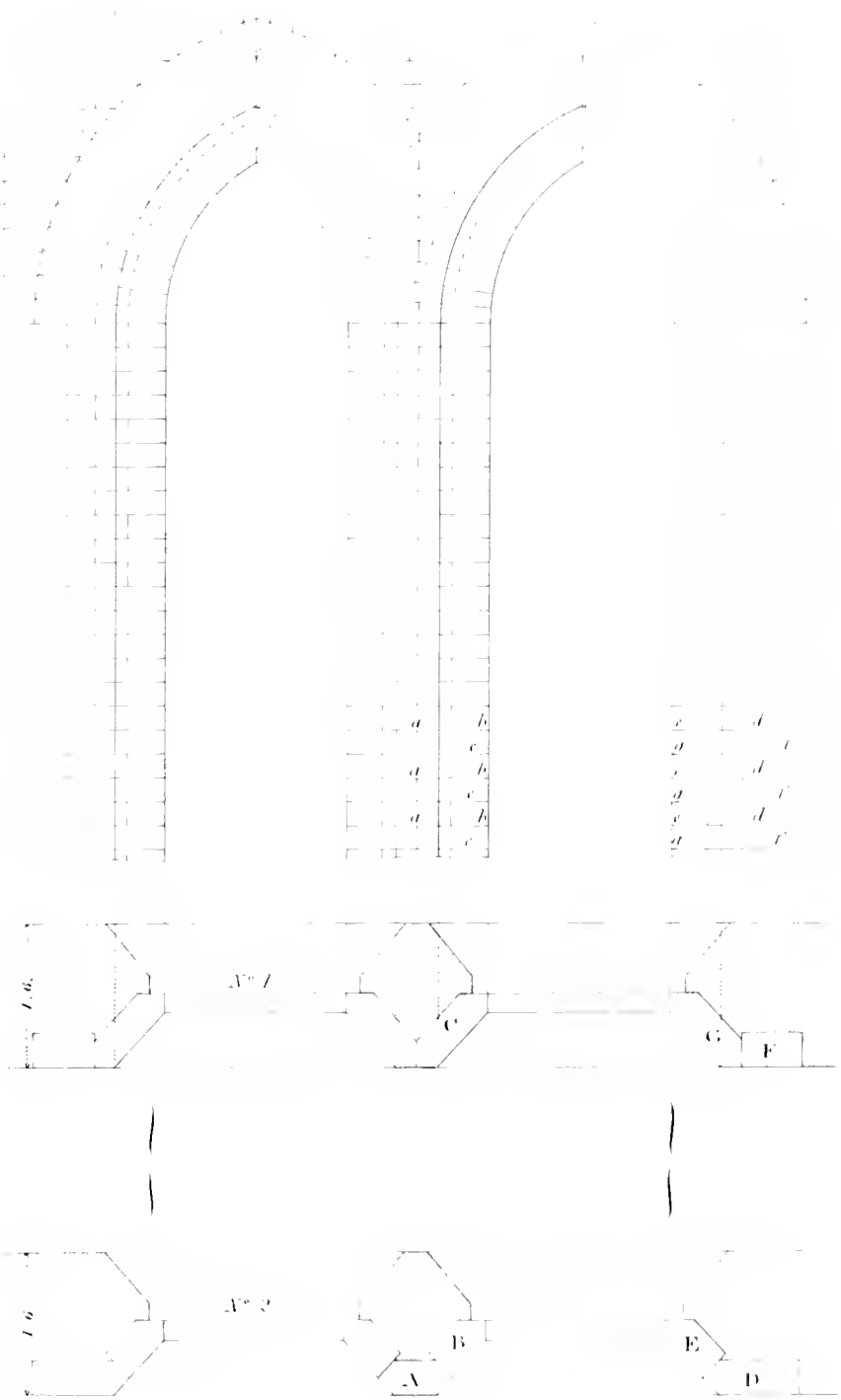
Fig. 2.



London Published by Thos. Kelly 17 Paternoster Row May

Gothic Window in Lotteridge New Church

Fig. 1



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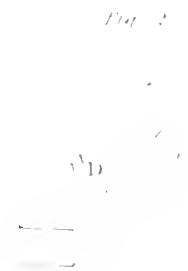

Fig. 3

Fig. 4

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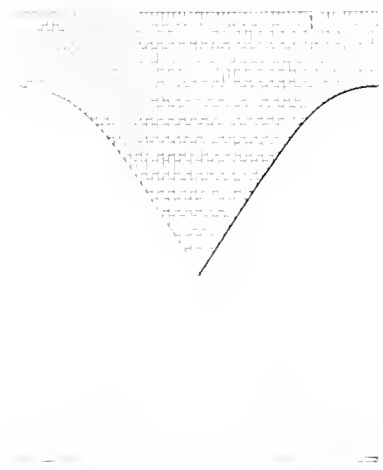
BRICKLAYING.

The Principles of Brick Vaulting as in common use.

Fig. 4



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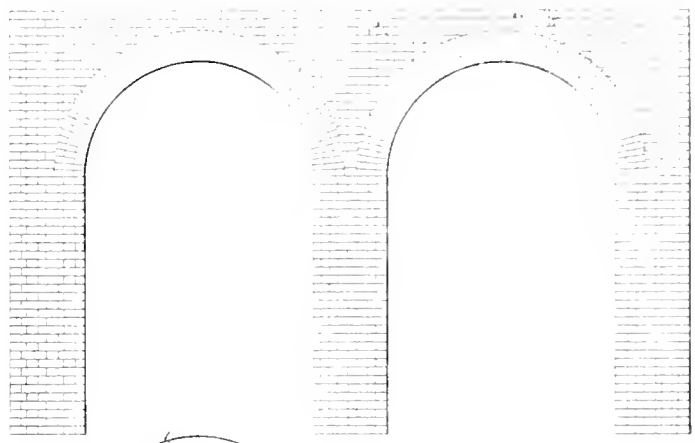

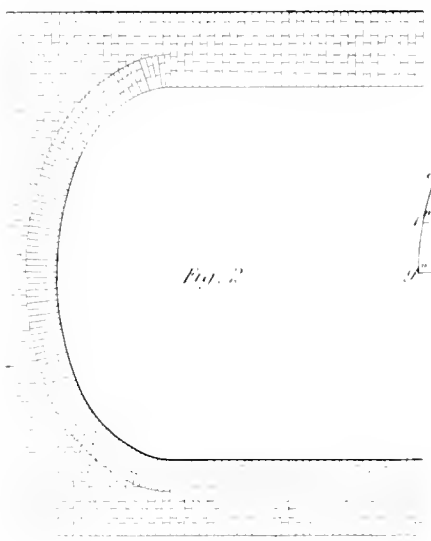

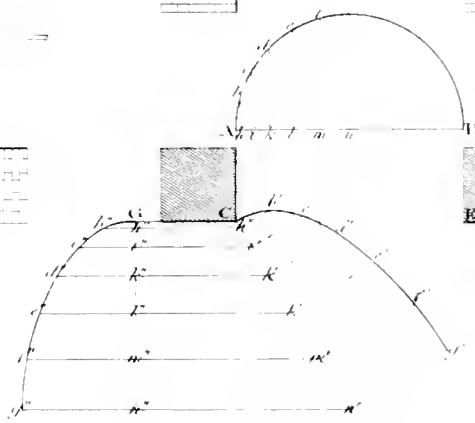

Fig. 3

Fig. 1

Fig. 5

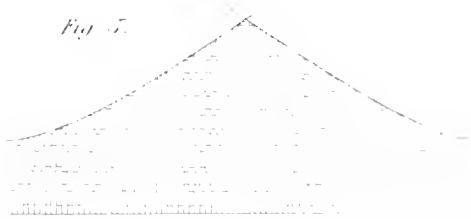

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Fig. 1

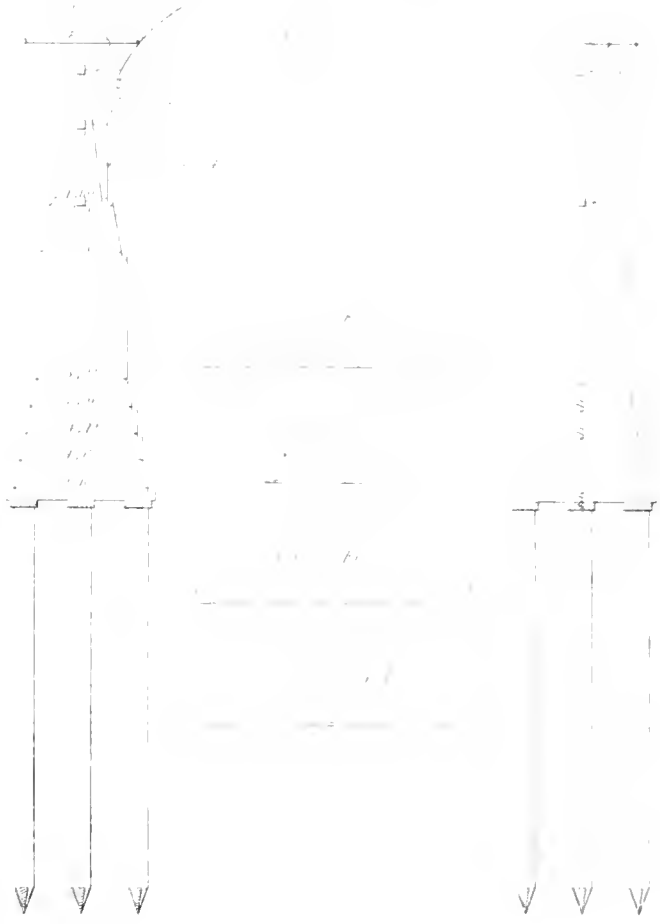

Fig. 1

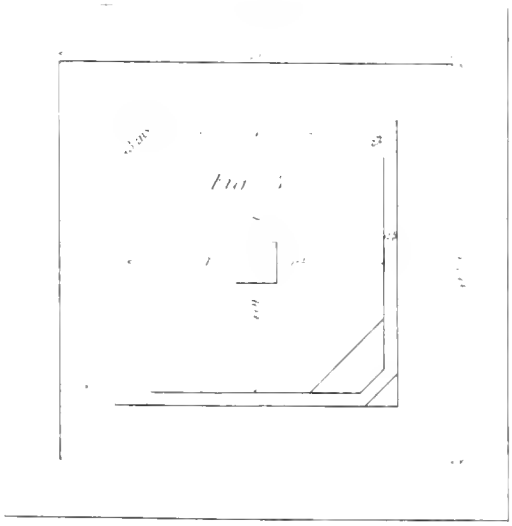

Fig. 1

Fig. 1

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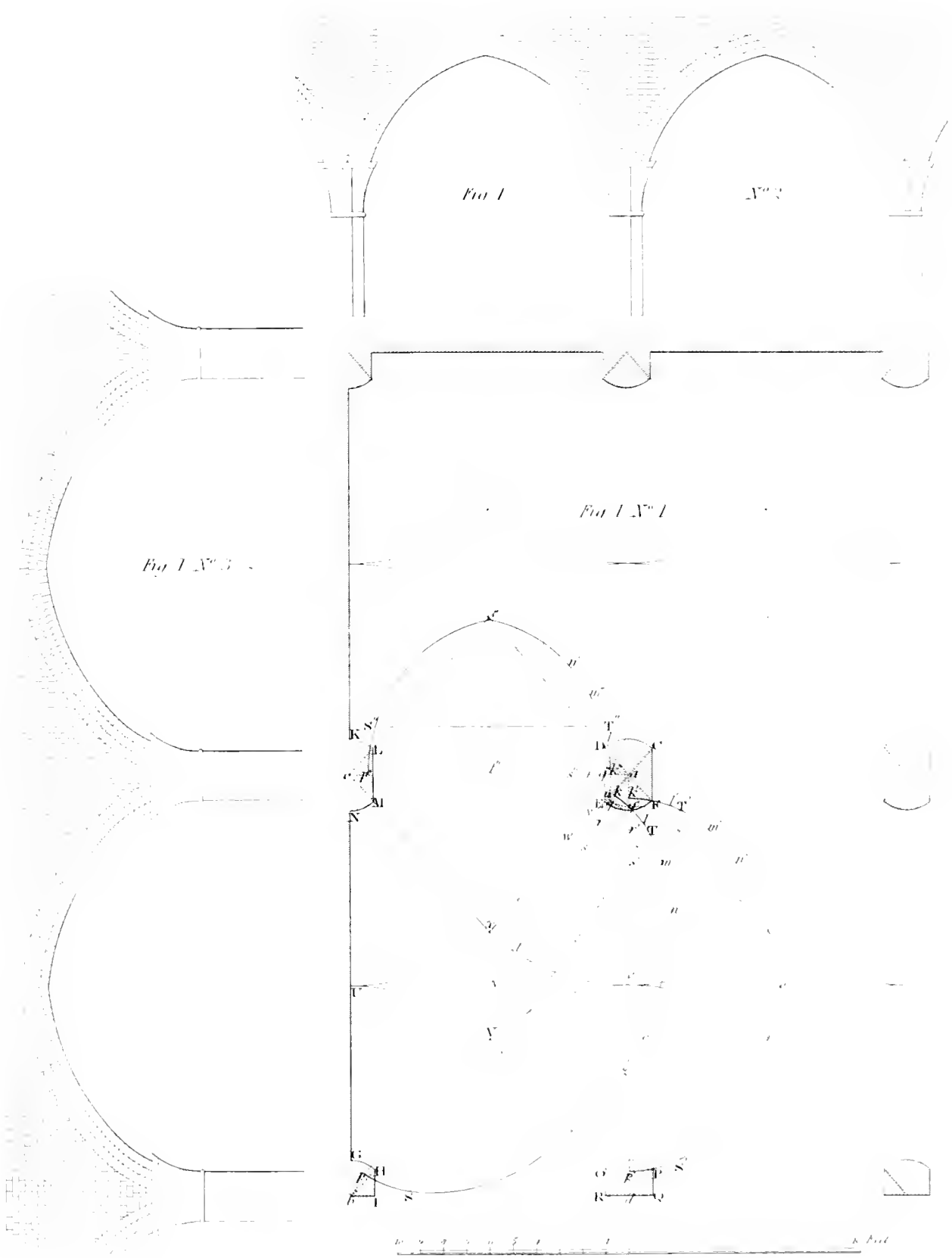
The Principles of Brick Vaulting as in St Katherines Docks Ex 1



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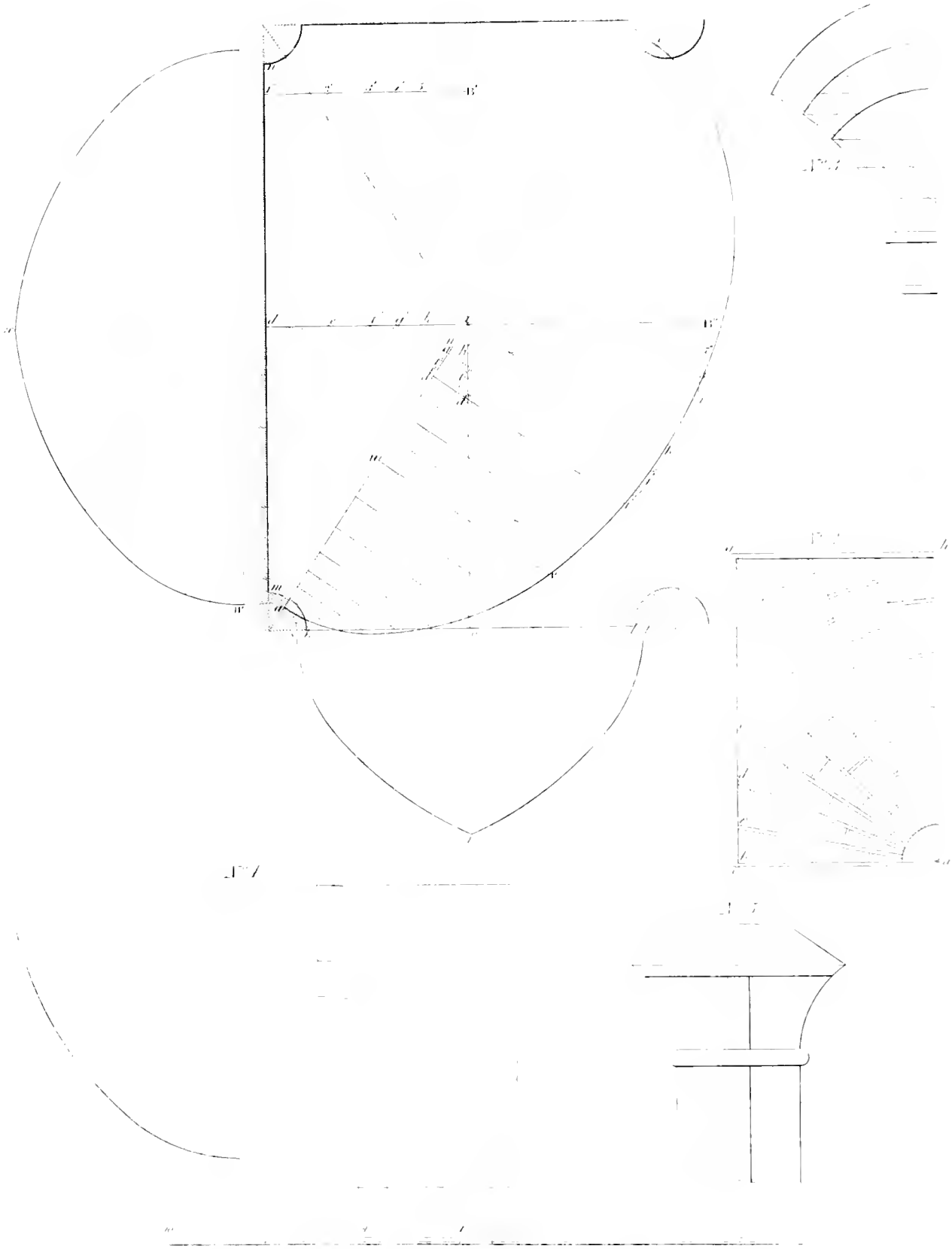
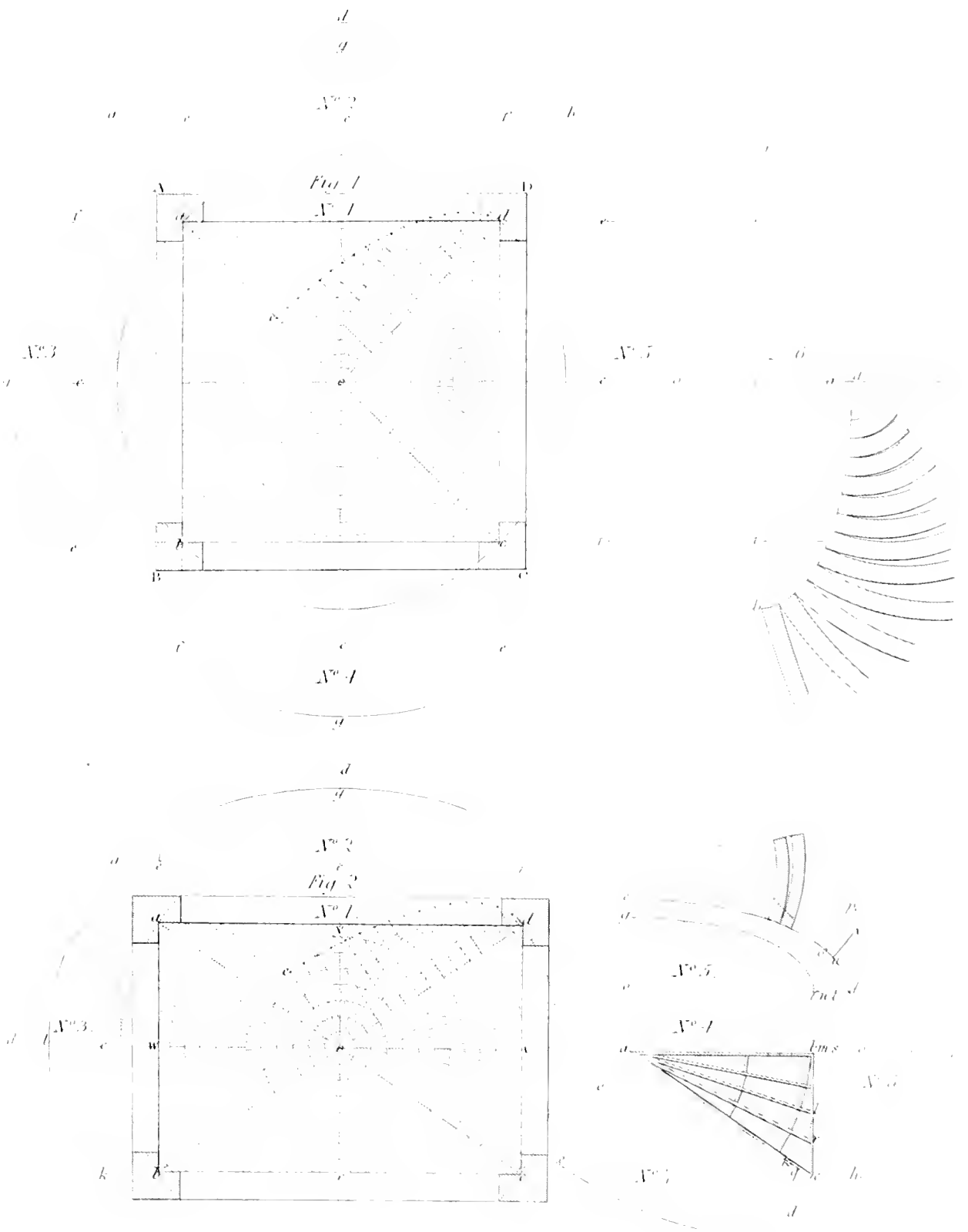


The Principles of Brick Vaulting as under the Hall at Christs Hospital



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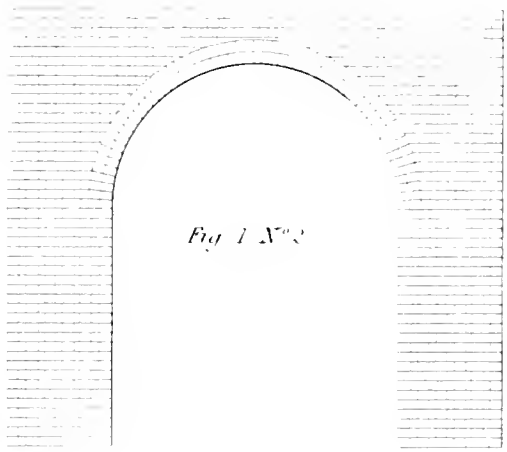
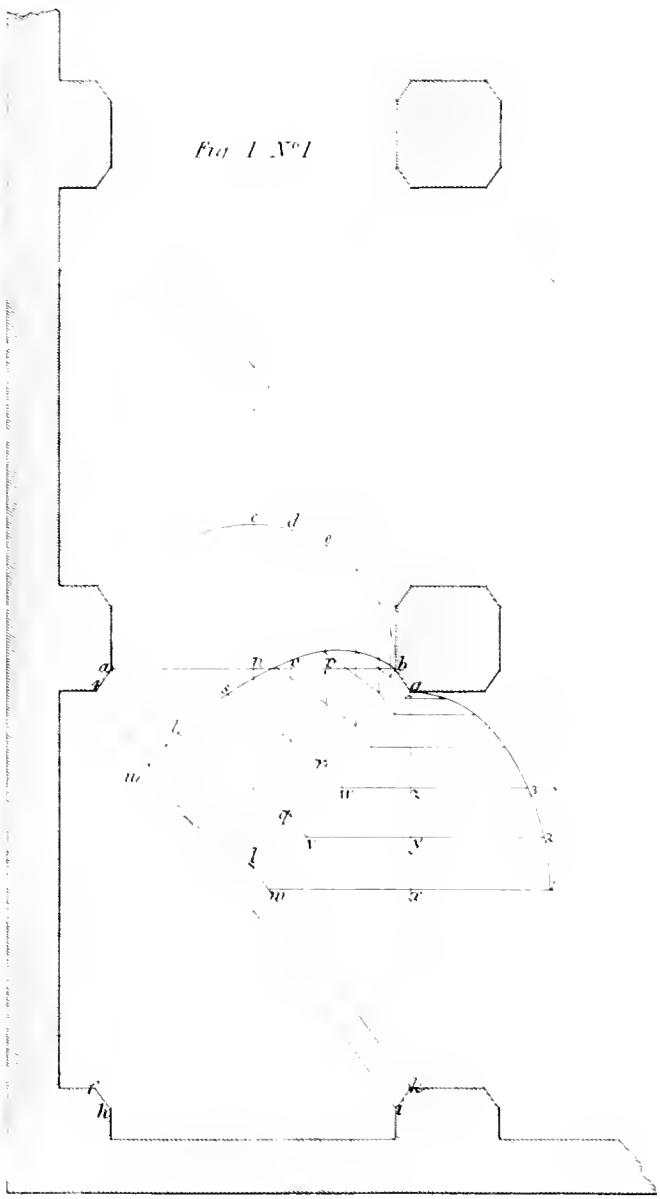


Fig. 1 N°1



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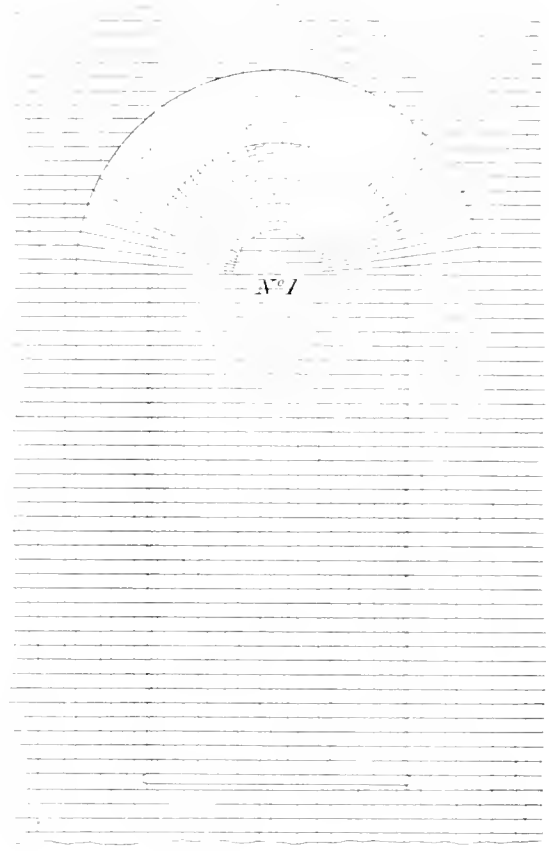

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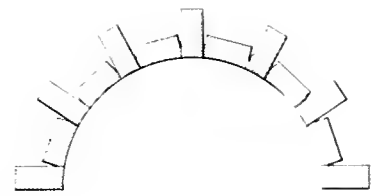

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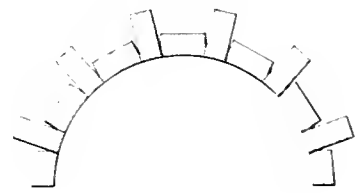

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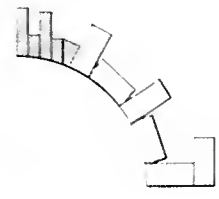

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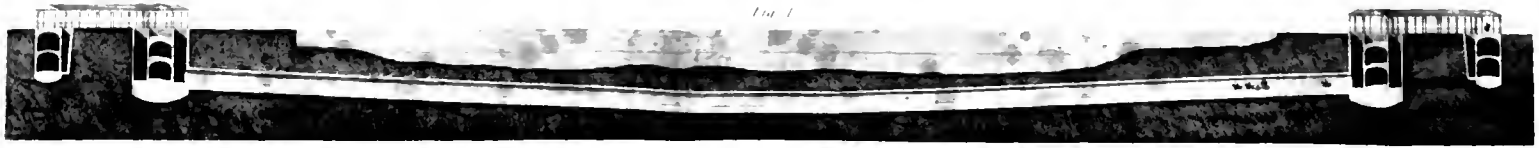
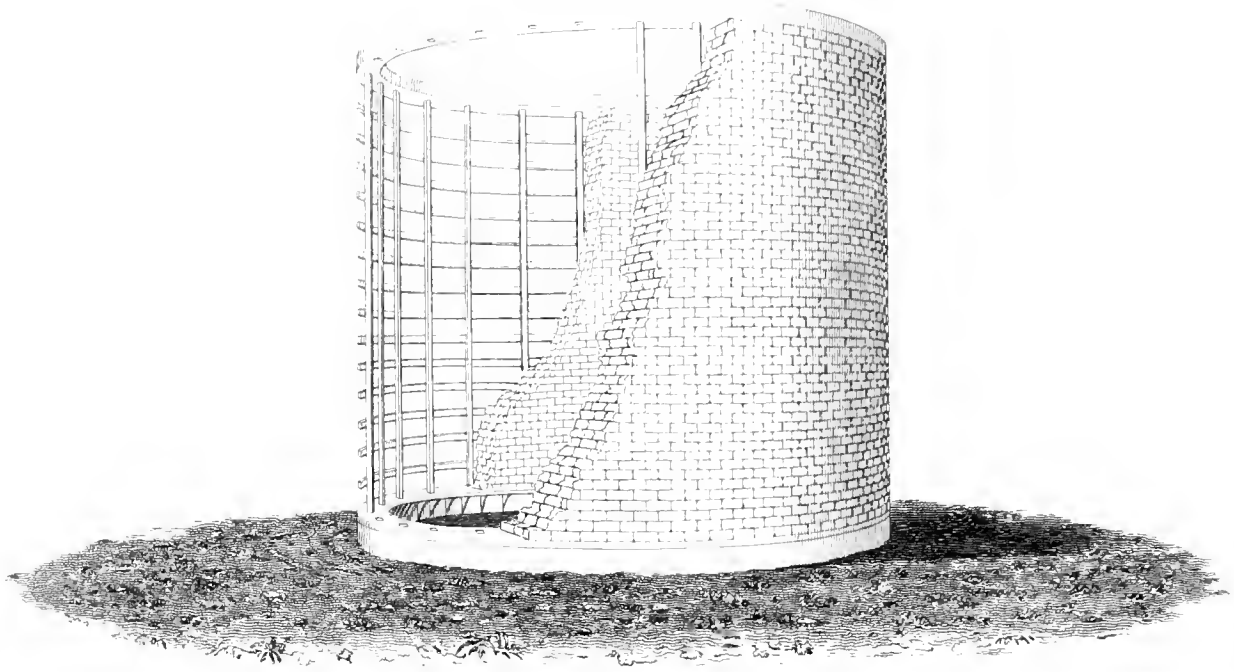


TUNNELING.

Fig. 1



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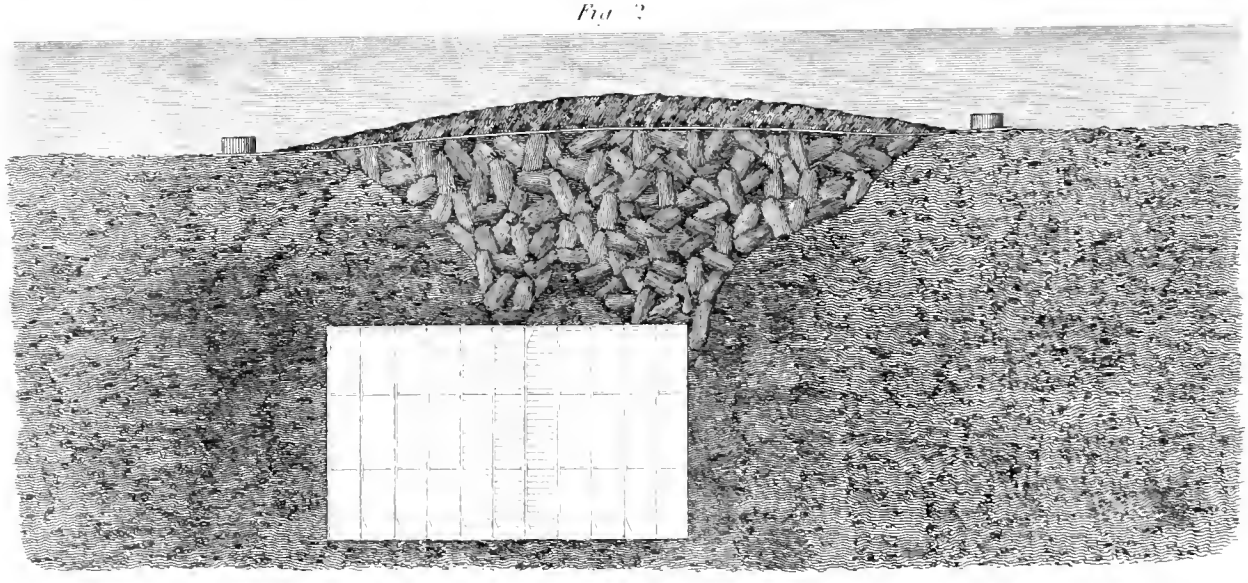

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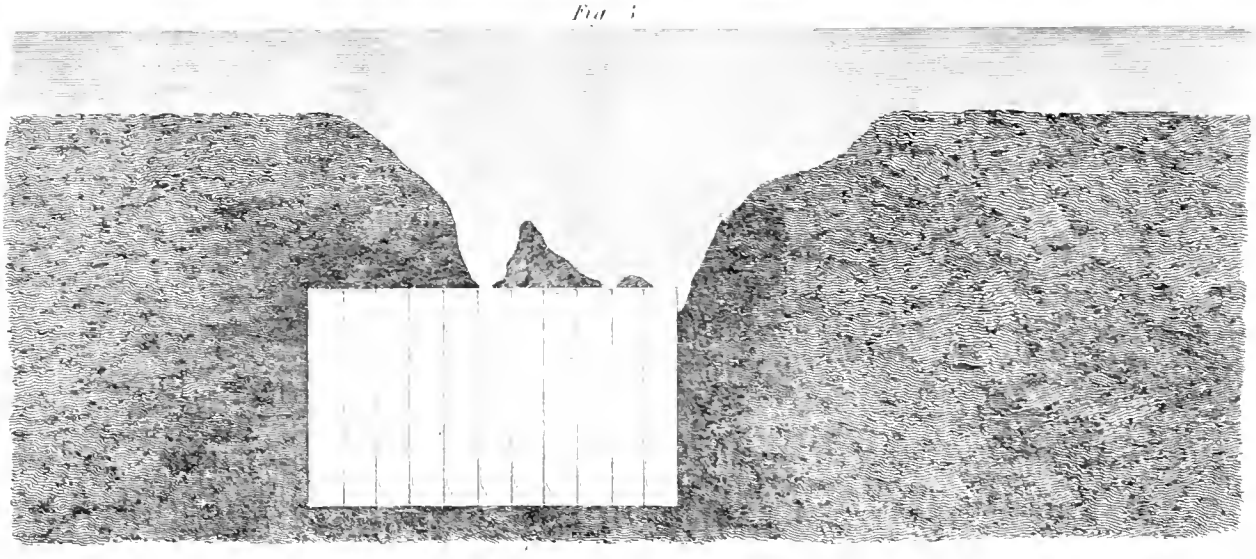
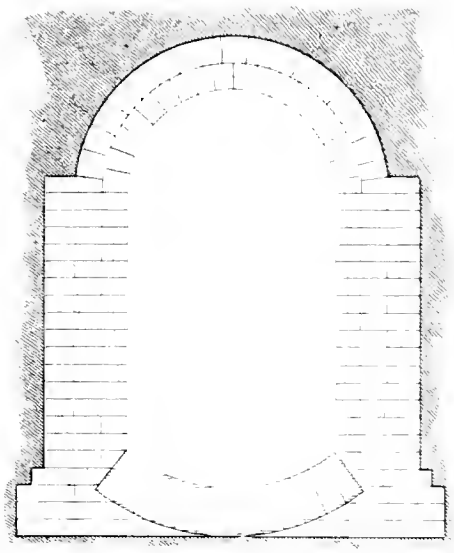


London Published by Thos. Kelly, 17, Paternoster Row, 1825.

TUNNEL

Fig 1



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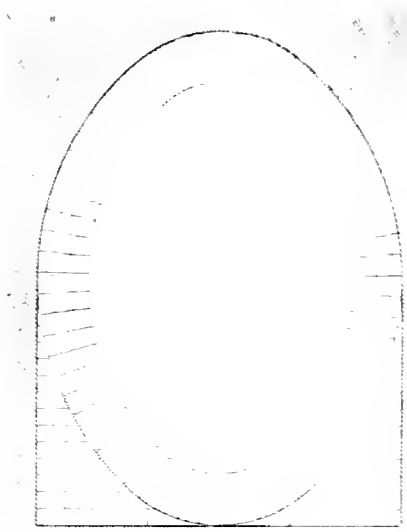
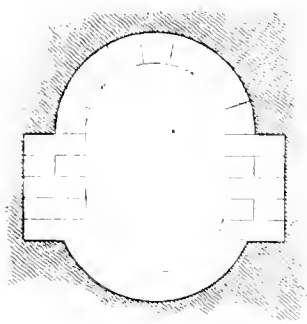


Fig 3



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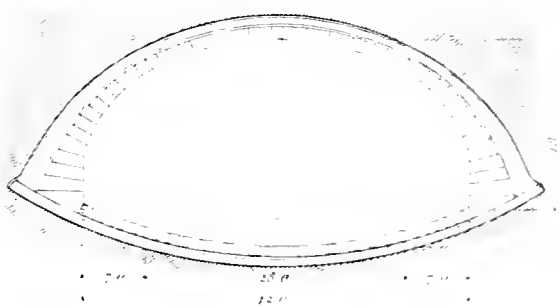

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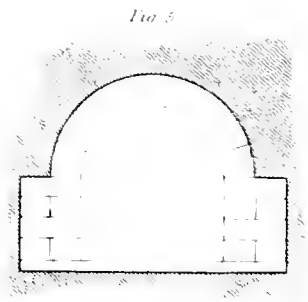

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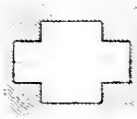

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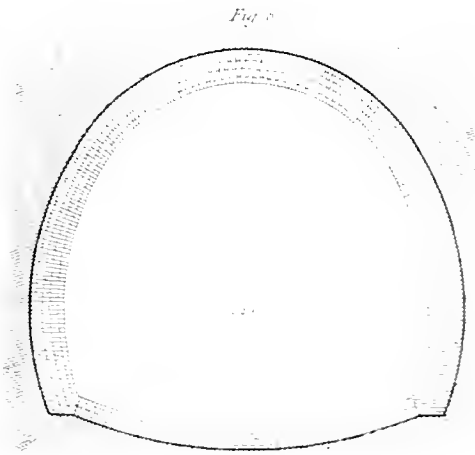

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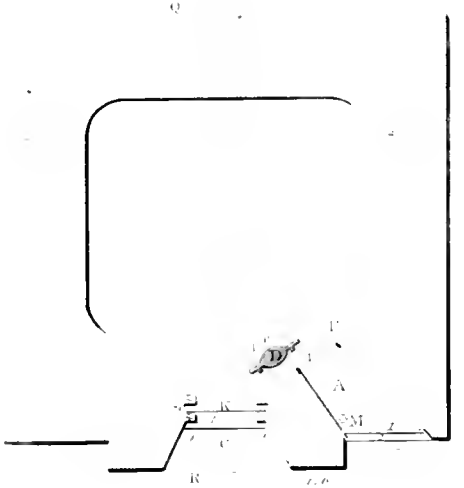

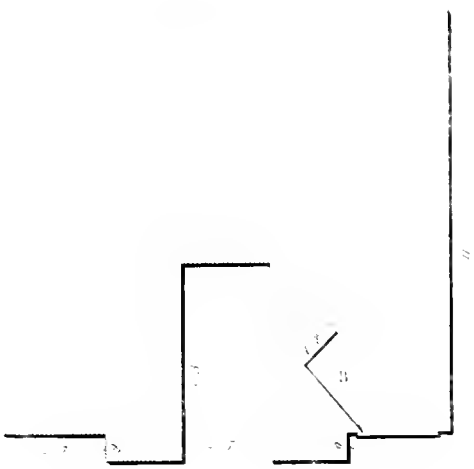

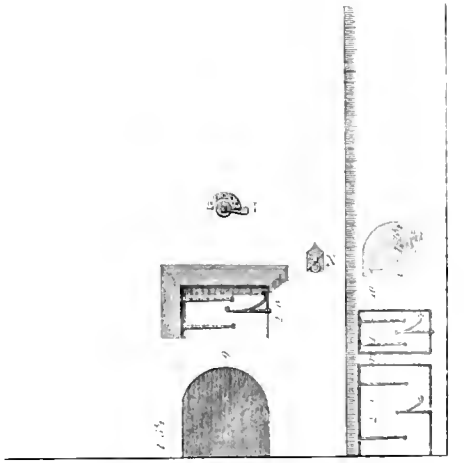

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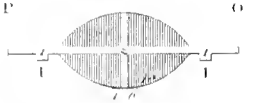

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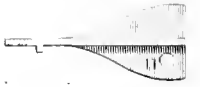

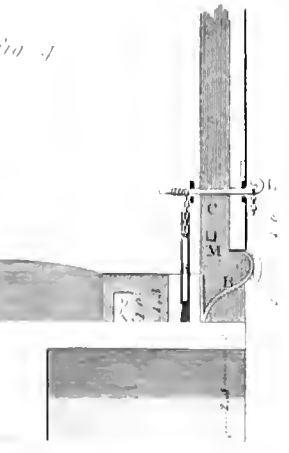

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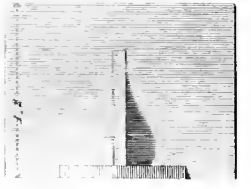

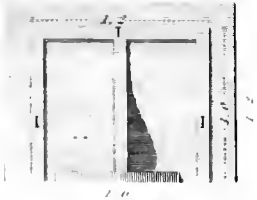

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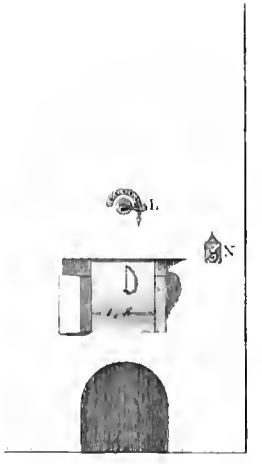
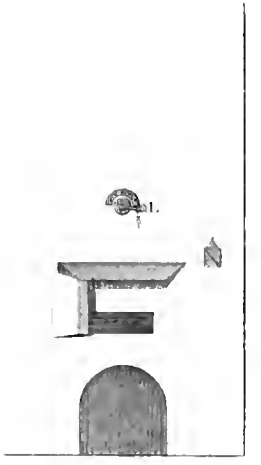
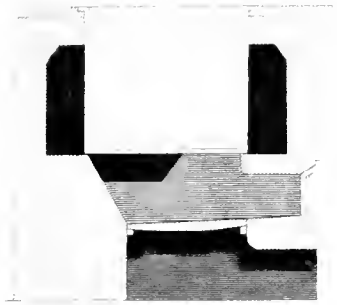




BOILER FIRE PLACES

Fig. 1



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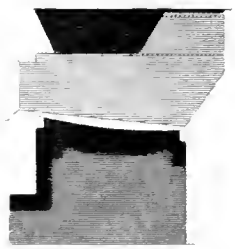

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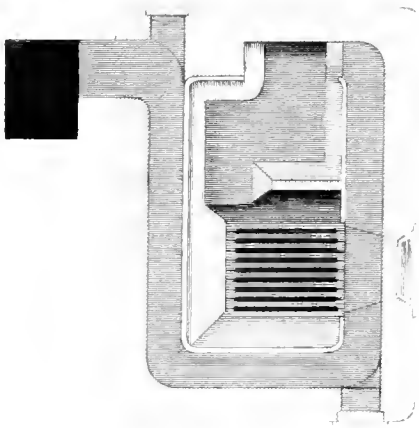

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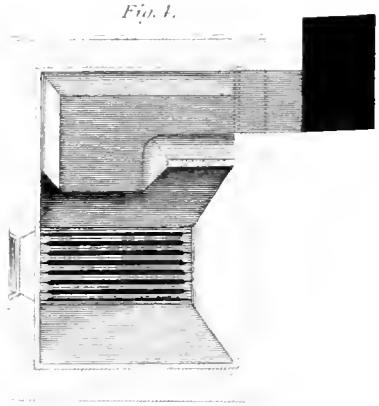
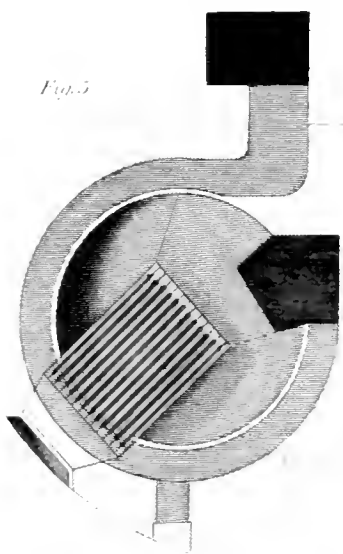


Fig. 6

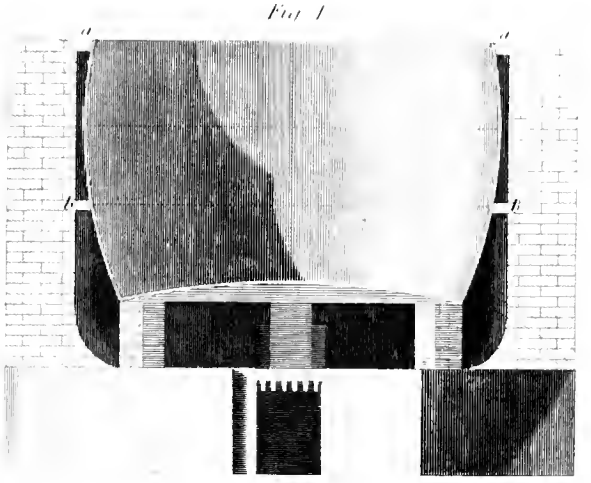
Fig. 5



BRICKLAYING.

On Fixing Copper Boilers.

Fig. 1



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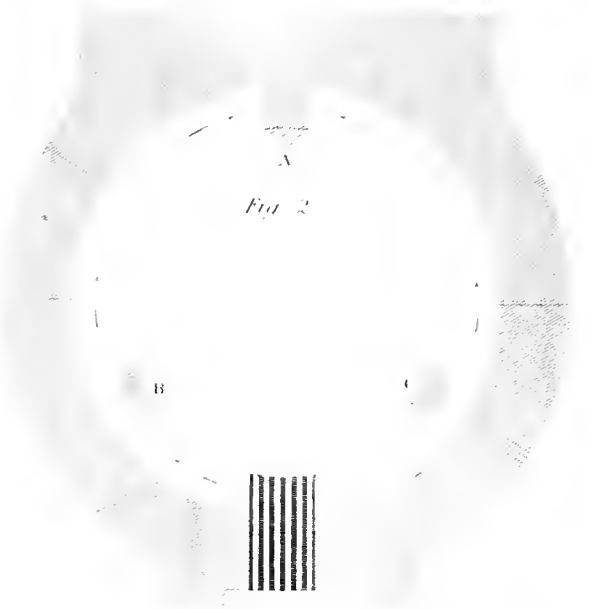

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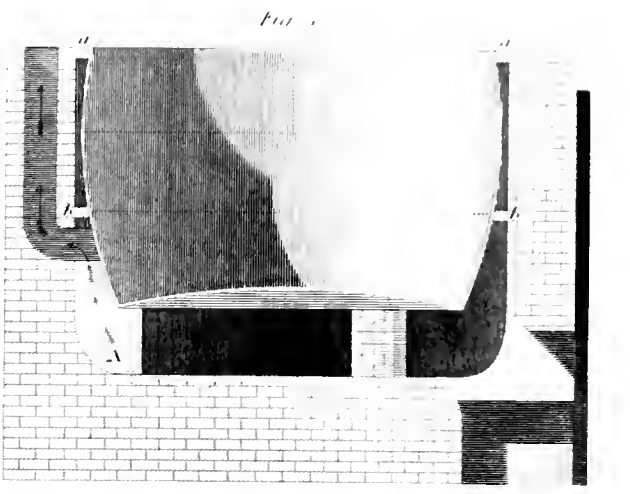

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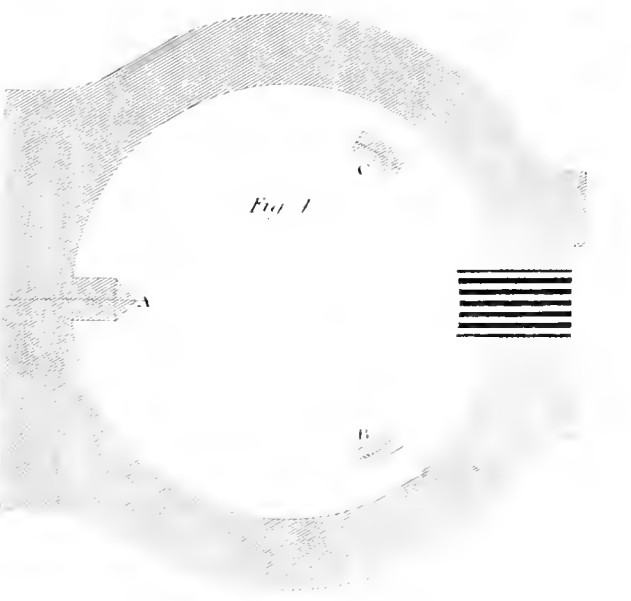

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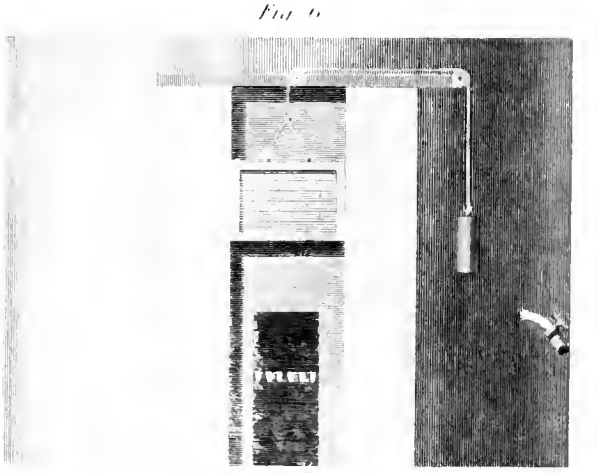

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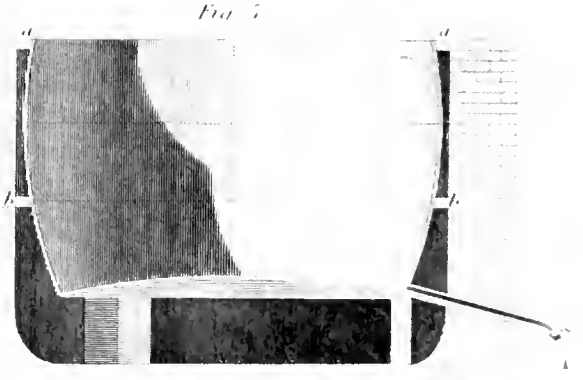

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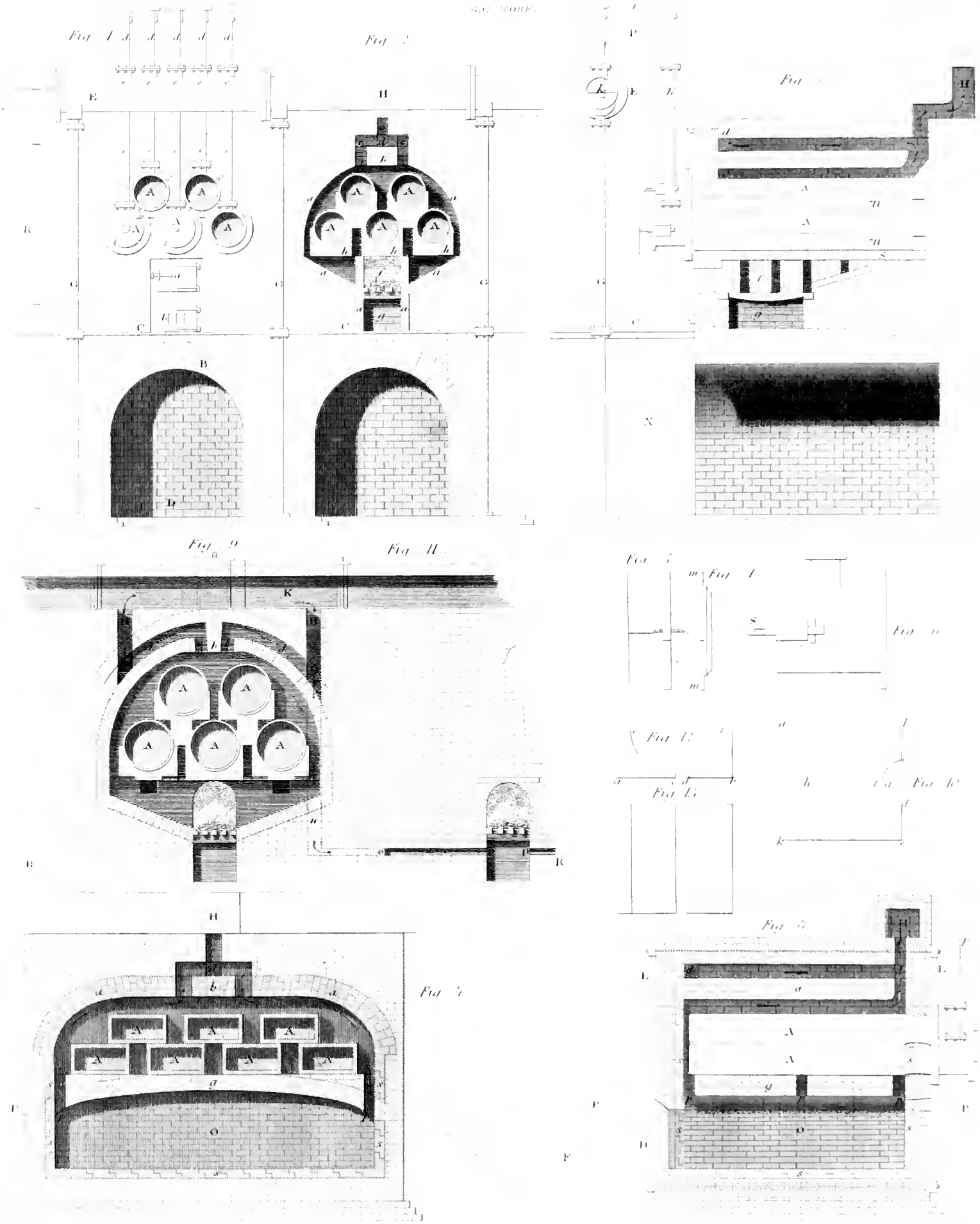

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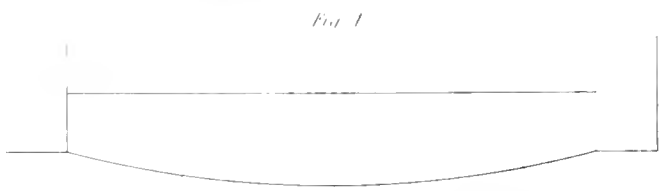
In Furnaces for Metallurgy

Fig 1

Fig 2



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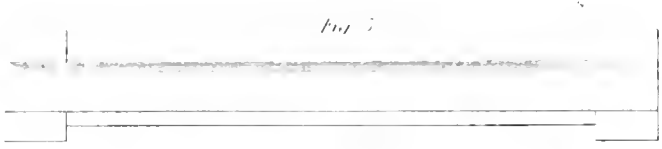
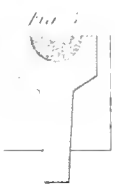


Fig 4

Fig 5



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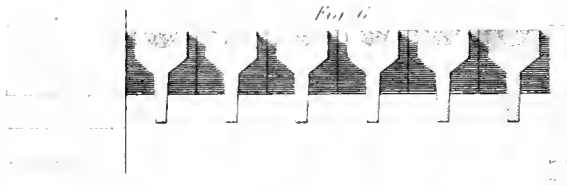
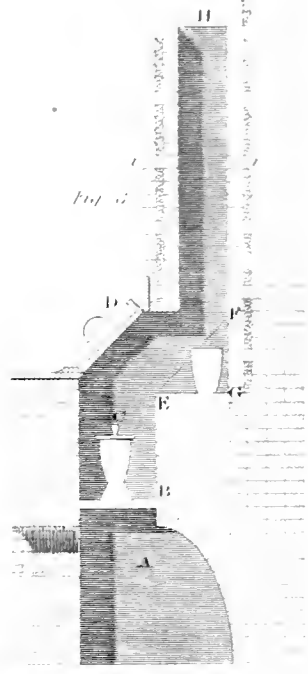


Fig 7

Fig 8



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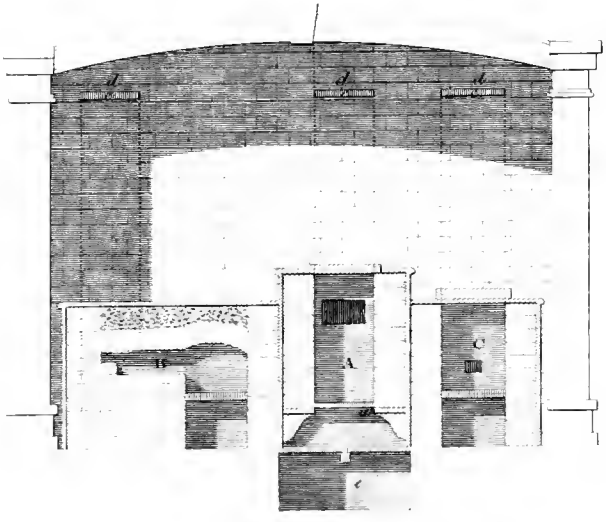

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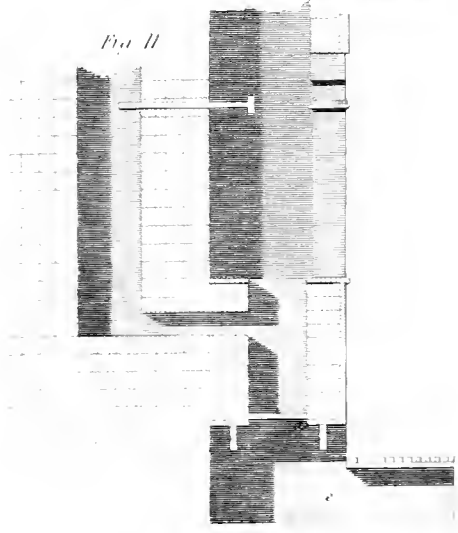

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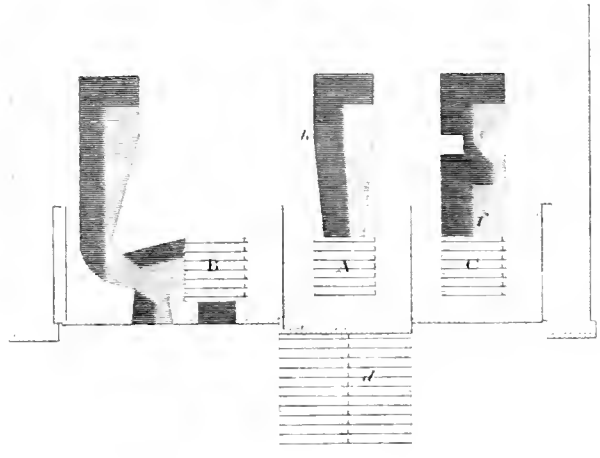

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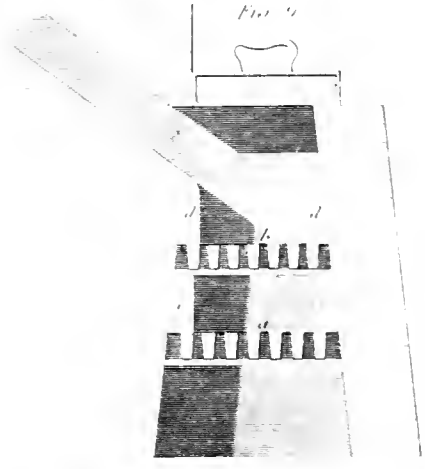

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Blast and Air Furnaces

Fig. 3

Fig. 2

Fig. 5

Fig. 5
Middle Rest

Fig. 1

Fig. 4

Fig. 7

Fig. 6

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Fig. 1

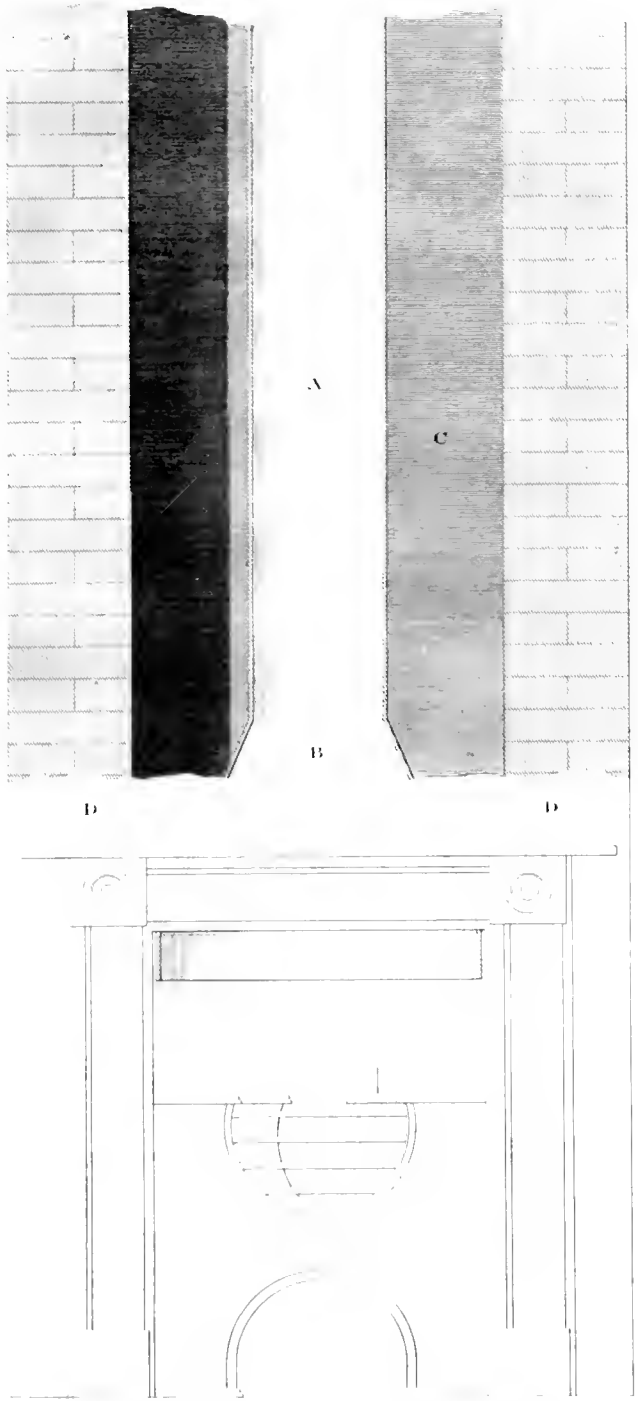
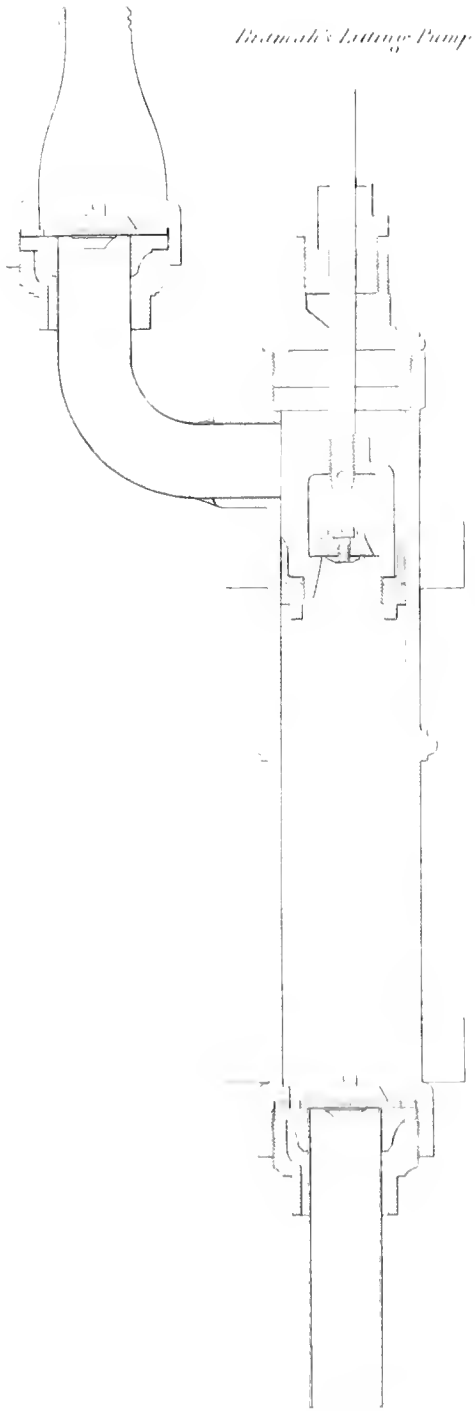


Fig. 2

Beamish's Lifting Pump



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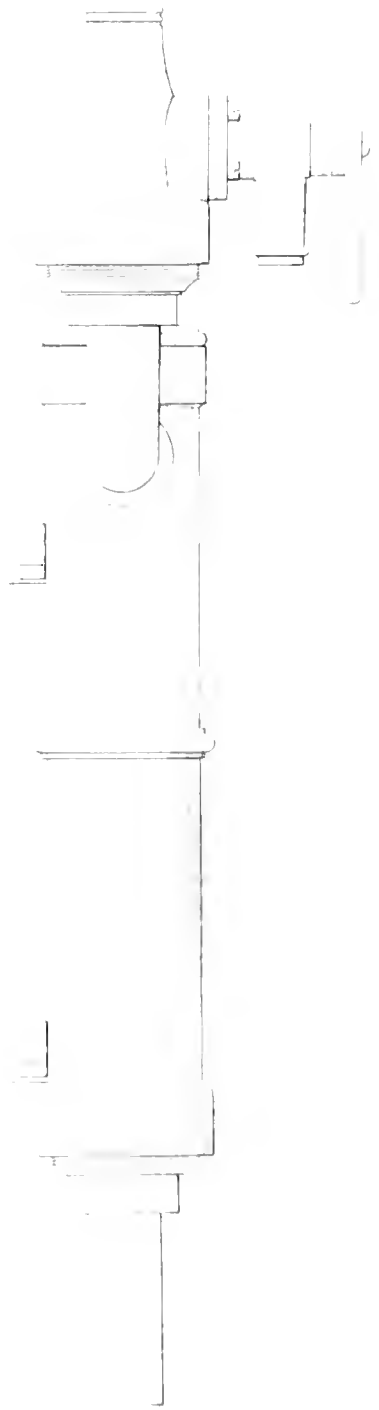
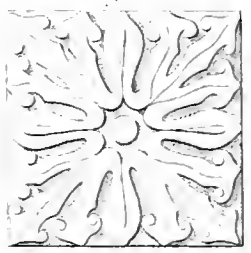


Gothic Style of Ornament

Fig. 1

Fig. 2



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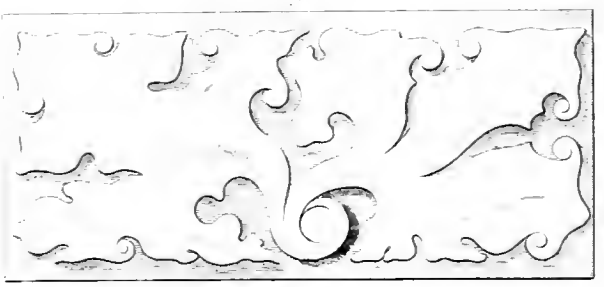

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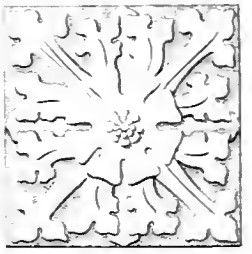

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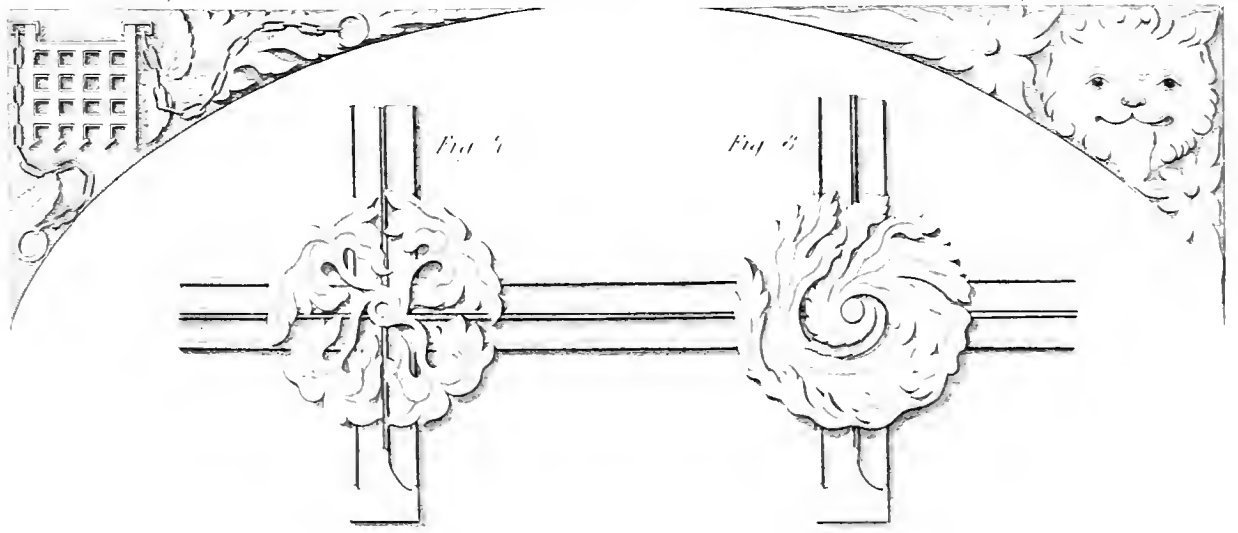
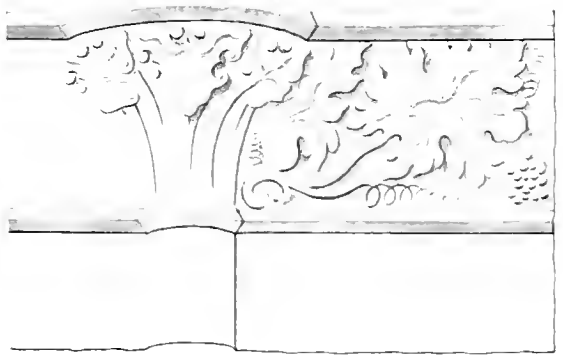


Fig. 6

Fig. 7

Fig. 8

Fig. 9



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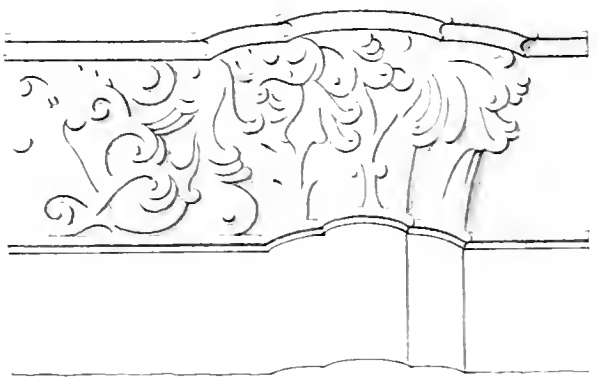

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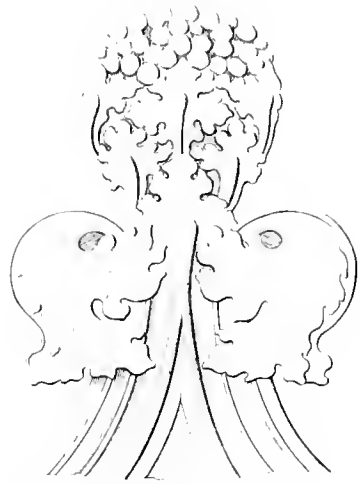
PLASTERING.

Gothic Style of ornament

Fig. 1



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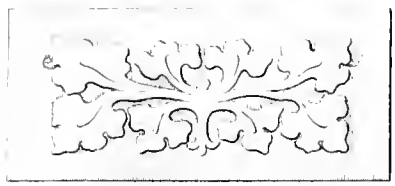

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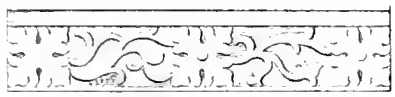

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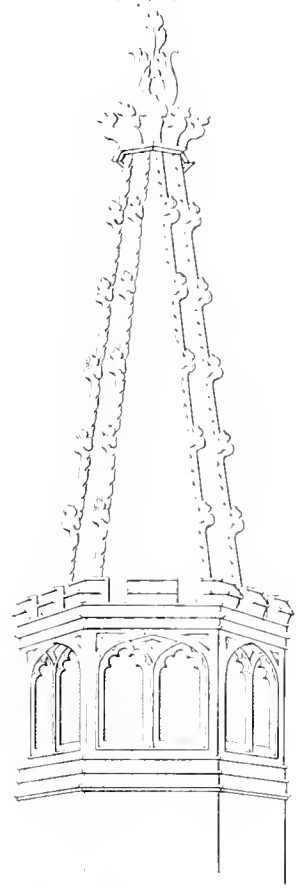
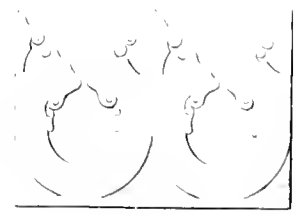


Fig. 6

Fig. 7



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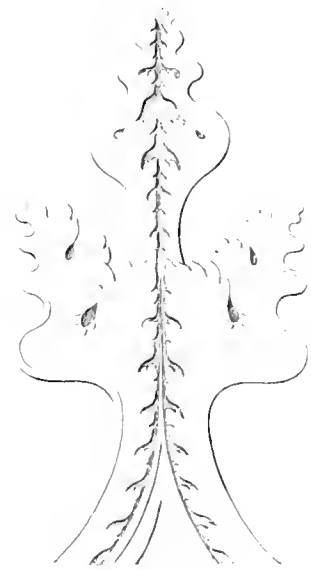

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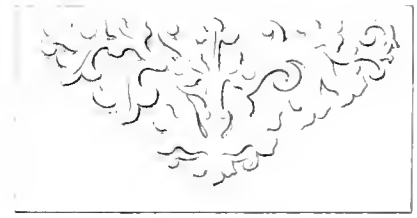

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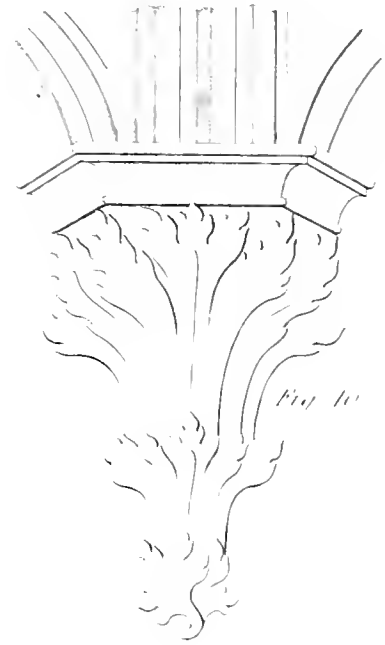
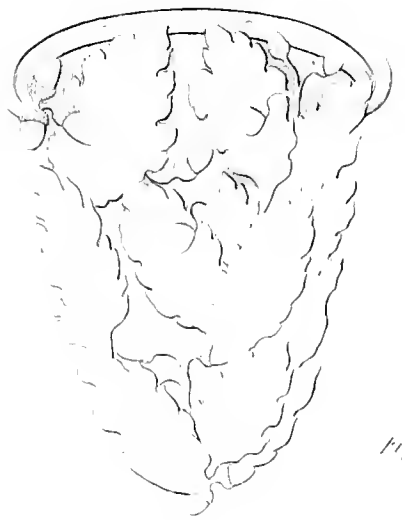


Fig. 4



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Elizabethan Style of Ornament

Fig. 1

Fig. 2

Fig. 3

Fig. 4

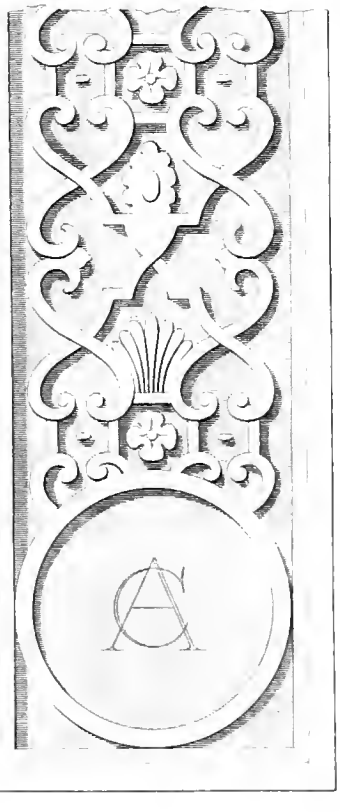

Fig. 6

Fig. 5.

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PLASTERING.

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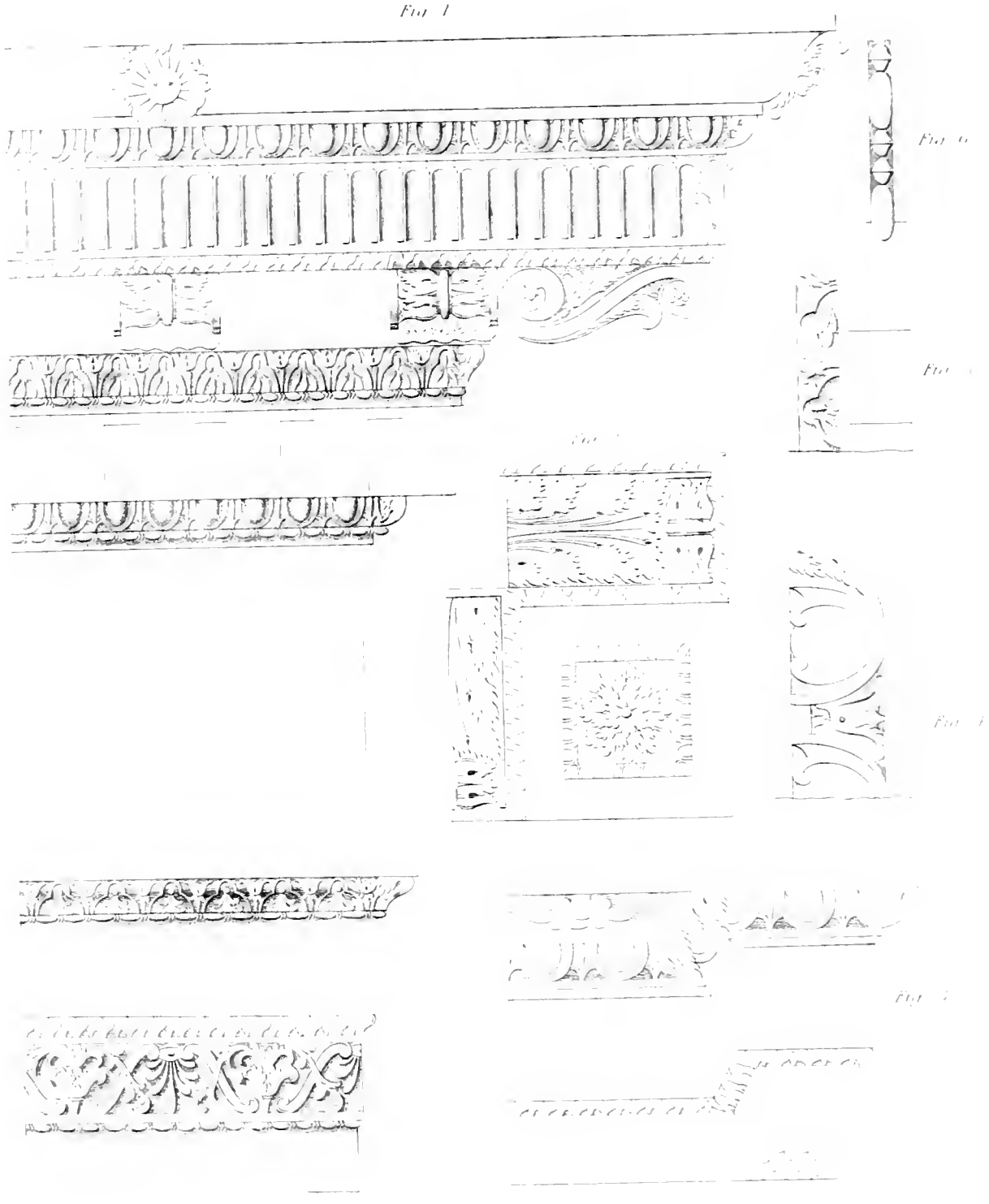


FRENCH ORNAMENT

Fig. 1

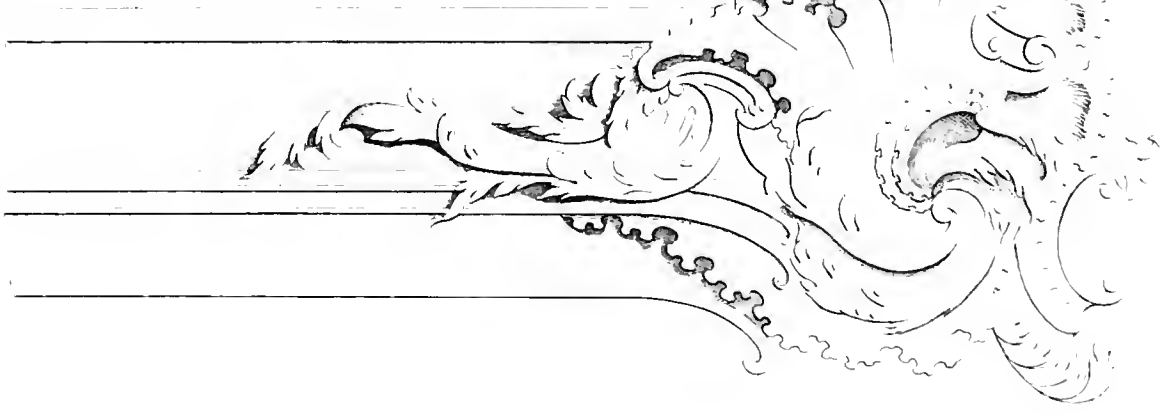
Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6



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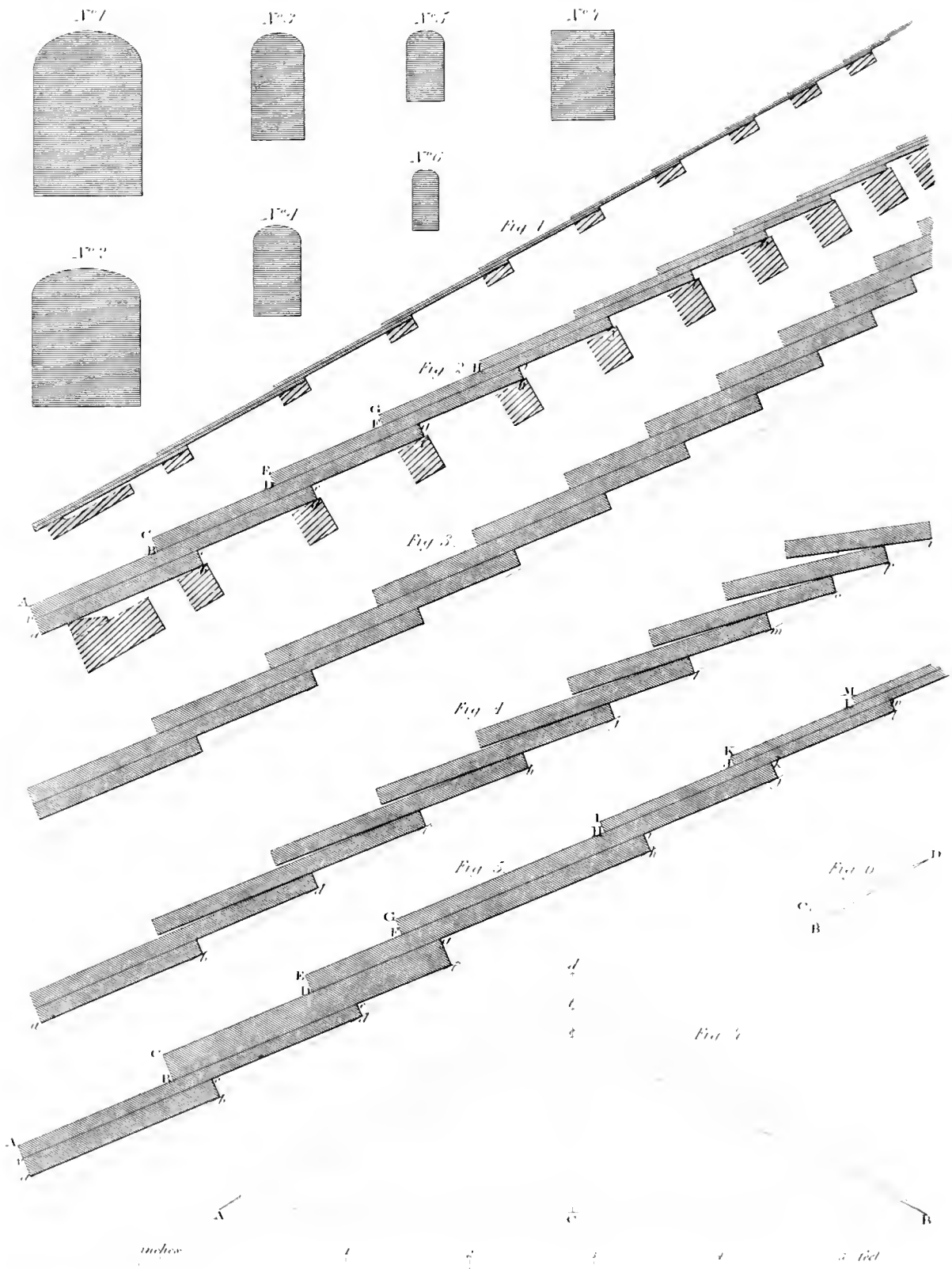

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